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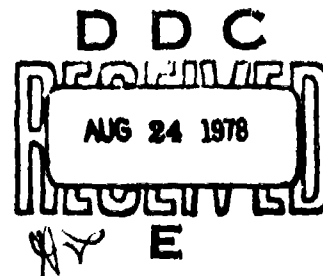
## BALLISTIC EVALUATION OF AIRCRAFT EXPLOSION SUPPRESSION MATERIALS

Charles L. Anderson  
Survivability/Vulnerability Branch  
Vehicle Equipment Division

January 1978

TECHNICAL REPORT AFFDL-TR-76-98

Final Report for Period December 1975 - March 1976



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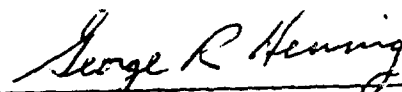
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Survivability	Fuel Tank Protection											
23mm HEI	Fuel/Air Ratio Measurement											
50 Cal API												
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) <p>This report presents the test results of a comparison of the ballistic performance of coarse and fine pore hybrid polyether urethane foams (blue), coarse and fine pore polyester urethane foams (red and yellow), Astrocated red foam, and a metal arrestor (Explosafe, made by Vulcan Industrial Packaging Limited, Canada). The materials were primarily tested wet (JP-4) with a stoichiometric mixture. Threats included 23-mm (HEI) and 50-Caliber (API). The report contains information about the test set-up, results, conclusions, and the fuel/air ratio measurement system.</p>												

## FOREWORD

The effort described herein was performed by the Survivability/Vulnerability Branch, Vehicle Equipment Division of the Air Force Flight Dynamics Laboratory. This effort was performed primarily to answer questions concerning the ballistic performance of hybrid polyether urethane foams as compared to polyester urethane foams. The program was performed at the direction of Mr. C. Anderson with the assistance of Mr. T. O. Reed of ASD/ENFET.

This program was performed, in part, for the Joint Technical Coordinating Group for Aircraft Survivability. All financial support and the large majority of manpower support was provided by AFFDL/FES under Project Number 4363, Task 436301, and Work Unit 43630141.

The efforts described in this report were performed during the period of December 1975 to March 1976.

The author gratefully acknowledges the assistance of Messrs. T. O. Reed (ASD/ENFET) and Mr. C. Harris (AFFDL/FES) for assistance in planning and managing this program; Mr. M. Gromosiak, Major Krobusek, Messrs. W. Gaines and W. Studebaker of the AFFDL Aircraft Survivability Research Facility for gunrange support.

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## SECTION I

### INTRODUCTION

The objectives of this program were to: (1) evaluate the ballistic performance of coarse and fine pore hybrid polyether urethane foams (i.e. blue foam) as compared to the coarse and fine pore polyester urethane foams (i.e. yellow and red foam); (2) perform a preliminary analysis of the ballistic performance of a new explosion suppression material called Explosafe (Vulcan Industrial Packaging Limited). The materials were tested using maximum flammable mixtures with mechanical damage and combustion overpressure as measures of performance.

The need to prevent explosions in the fuel tank ullage (the space above the fuel level which contains air and fuel vapors) of combat aircraft is of major importance if a survivable aircraft is to be obtained. Since the fuel system of any combat aircraft is the most vulnerable portion of the aircraft and occupies such a large fraction of the aircraft, it can be seen why a system to prevent explosions in the fuel tank ullage is the single most important survivability defense concept. The polyester urethane reticulated foams were introduced in the late 1960's and represented a significant contribution to the survivability of any combat aircraft using this material.

The primary drawback from using the foam is its weight and volume penalties, but nevertheless, the foam has been, and will continue to be incorporated into combat aircraft because of its effectiveness in

preventing explosions. This polyester urethane, in use since the initial application of foams in fuel systems, progressively undergoes chemical degradation when exposed to an elevated heat/humidity environment. This chemical degradation of the foam leaves it with little or no physical integrity.

This fact came to the forefront in the conflict in SEA due to the high humidity/temperature environment encountered there. The problems associated with the degrading of the foam succeeded in placing a lot of emphasis on development of new materials that do not degrade (i.e. has better hydrolytic stability). The blue foam (both coarse and fine pore) tested in this program is a prime candidate for replacing the polyester urethane foams. The blue polyether urethane foam is far less prone to degradation effects in a high temperature/humidity environment compared to the polyester. The currently formulated blue foam suffers from effects due to fuel environments. The foam swells in fuel and there is a decrease in tensile strength. It was thought that these characteristics would lead to a less viable flame and explosion suppressor. The reservations concerning the polyether foam dictated that a ballistic evaluation be performed to verify its performance.

Another type of material which has entered the picture recently is called "Explosafe". The "Explosafe" had been subjected to minimal ballistic testing prior to this program and therefore many questions existed as to its performance against various projectiles.

## SECTION II

### TEST DESCRIPTION

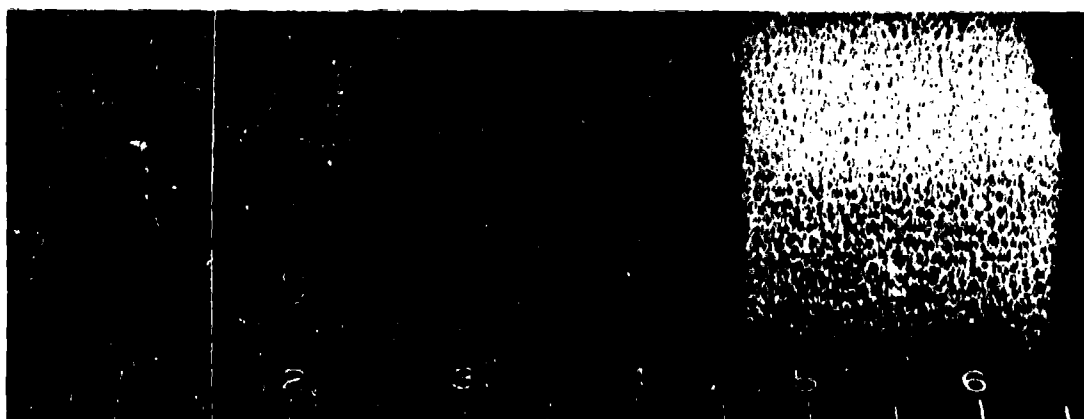
#### 1. EXPLOSION SUPPRESSION MATERIALS

The materials tested in this program include the polyester urethane reticulated foams, the hybrid polyether urethane reticulated foams, a polyester urethane reticulated foam coated with Astrocoat, and an aluminum metal flame arrestor called Explosafe. These reticulated foams will subsequently be referred to as polyether and polyester foams. The polyester foams were tested using coarse (6 pores per centimeter (ppc), yellow) and fine (10 ppc, red) pore foams. The polyether foams were tested using coarse (6 ppc) and fine (10 ppc) pore foams. Both pore size polyether foams were colored blue. Pertinent data on these foams are presented in Appendix IV. The polyester foam is presently covered by Military Specification MIL-B-83054A. The polyether foam will be added to this specification in the future. The Astrocoated foam tested here was made by coating buns of the red polyester foam. The coating process consists of dipping a bun of foam in a polyether urethane solution. This coating caused the red foam to take on a nearly black color. The Astrocoat was developed by Olin Matheson and the process by which the foam is dipped in the Astrocoating solution was developed by Hughes Aircraft under a contract from NASA, Ames.

2. The Explosafe aluminum metal arrestor is manufactured by Vulcan Industrial Packaging Limited, Canada. The material consists of single sheets of aluminum 0.076 mm thick which have several short cuts at

regular intervals to produce a single sheet of expanded metal mesh. These sheets are then stacked in bundles. Samples of all materials are shown in Figure No. 1.

There were two different configurations used for testing the explosion suppression materials. The first was the "egg crate" voiding configuration which is depicted in Figure No. 2. This configuration consisted of 27 rectangular voids (17.8 cm x 17.8 cm x 20.3 cm) cut in the foam (resulting in 22.6% void) and installed in the test specimen as Figure No. 2 depicts. The second was the solid packed configuration which was identical to that depicted in Figure No. 2 except that there were no voids cut in the foam. The Explosafe was tested in the solid packed configuration only and was installed in 14 bundles, each approximately 6.5 cm thick.



Red Foam (10 ppc)

Fine Pore Blue Foam (10 ppc)



Yellow Foam (6 ppc)

Coarse Pore Blue Foam (6 ppc)



Astrocoated Red Foam (10 ppc)

Explosafe Metal Arrestor

Figure 1. Explosion Suppression Materials Tested

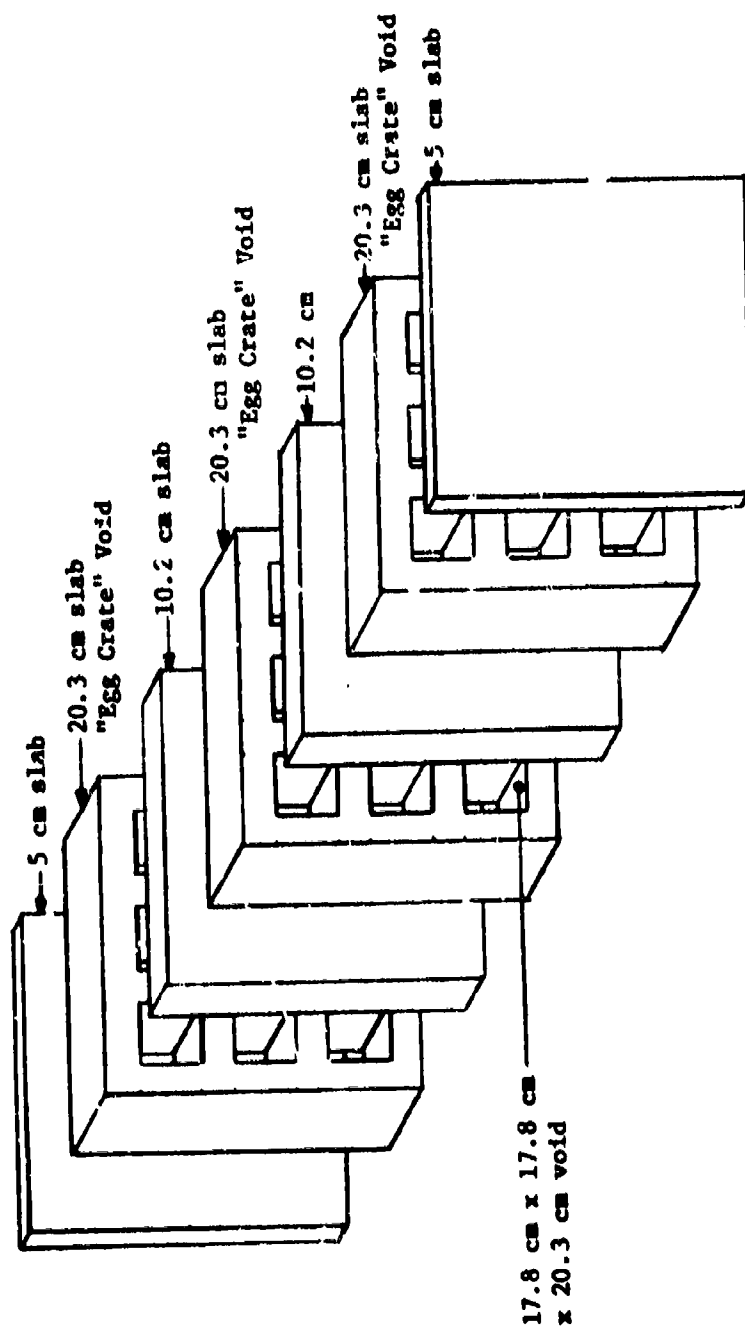


Figure 2. "Egg Crate" Voided Foam Installation

## 2. TEST SPECIMENS

The tests described in this report were performed with two Tank Wall Simulators (TWS). TWS No. 1 was used for baseline tests and TWS No. 2 was used for comparison testing of the explosion suppression materials. Both TWS's were of identical basic construction consisting of four 6.35 mm thick reinforced steel sides with provisions for mounting replaceable aluminum test panels on the front and rear. The TWS is symmetrical from front to rear and side to side. See Figure No. 3. The tank was approximately a 0.91 meter cube having a total

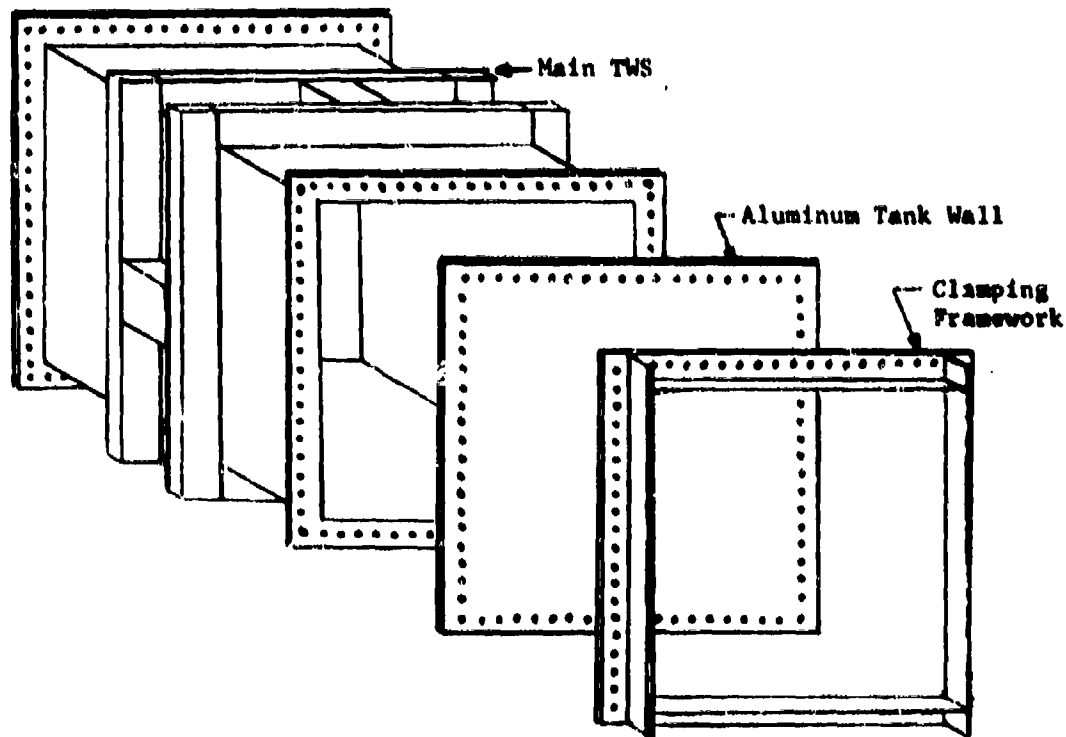


Figure 3. Recte Tank Wall Simulator (TWS)



volume of 0.75 cubic meters. There were provisions for fueling and defueling at the top and bottom of the tanks. Several other small fittings were installed for pressure taps, thermocouples, etc. Two different materials were used for impact and exit panels; 7075-T6, 2.033 mm thick and 2024-T3, 1.803 mm thick. These panels were appropriately 91 cm x 91 cm single sheets of aluminum with no stiffeners incorporated. The TWS's were instrumented with two (2) pressure transducers for measuring combustion overpressures. Primarily, the transducers used were Statham Model PG 822 bonded strain gage type pressure transducers. Also used during the beginning of the program, were PCB Model 202A quartz piezoelectric pressure transducers. These piezoelectric transducers were used because the pressures from the HEI blast were unknown and the dynamic range far exceeded that of the strain gage type. These transducers were generally connected to the TWS via a 6 mm diameter flexible tube 35 cm long to isolate the transducers from shock and vibration. There were 4 thermocouples installed in the tank to monitor fuel and ullage temperatures. See Figure No. 4 for instrumentation location and installation diagram.

TWS No. 1 incorporates a small electric fan driven by an induction motor which produces no sparks. This fan was installed inside the tank approximately 15 cm from the top and front of the tank so that it would be out of the blast cone of the HEI and avoid damage. The fan was powered by 115 VAC and had a flow rate in excess of 14 liters/second which served to "mix-up" the ullage gases. This insured a virtually homogeneous mixture of air and fuel vapors. This fan was removed for

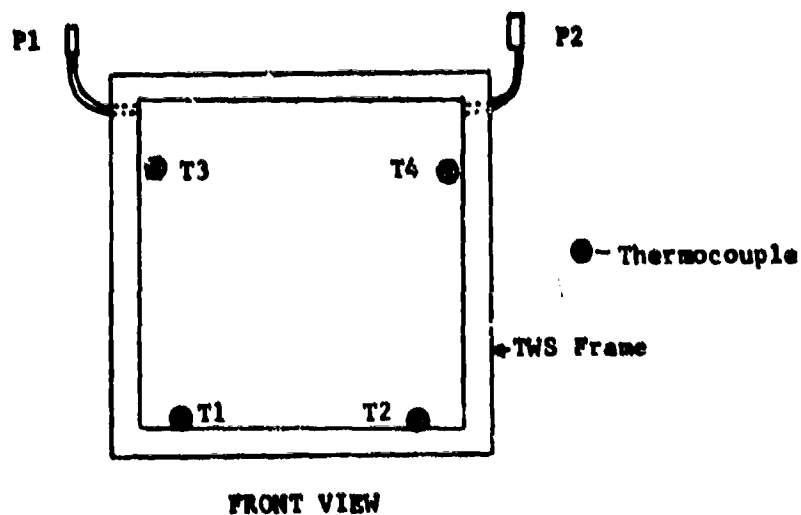


Figure 4. Instrumentation Locations

tests that did not require a stoichiometric fuel/air ratio. TWS No. 1 was used for; baseline tests with air only, **for** tests with no explosive vapors, and tests with no foam but with explosive vapors.

TWS No. 2 was used for all the tests with the explosion suppression materials which required stoichiometric fuel/air ratios. The primary difference between TWS No. 1 and TWS No. 2 is the elaborate circulation system incorporated in TWS No. 2. Due to the presence of internal foam inside the tank, the use of a fan as in TWS No. 1 was precluded. The system devised is depicted in Figure No. 5. It is composed of two electric fans in a 17.8 cm diameter duct above tank to provide circulation and eight 6.4 cm diameter pipes on each side of the tank for pulling ullage gases out and returning them to the other side of the tank. Valves were incorporated into each of the 16 pipes to isolate the circulation system prior to weapon firing. This system was sized to provide in excess of 14 liters/sec flow in order to adequately mix

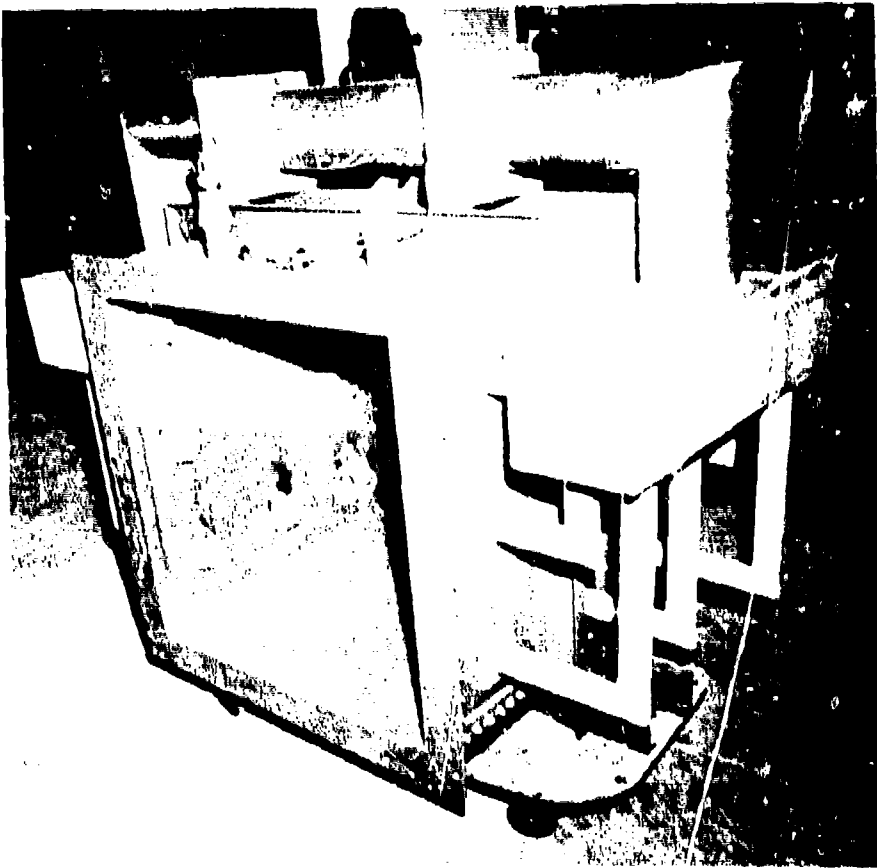


Figure 3. PFS No. 1 and Initial Circulation System

the ullage gas and thereby ensure a homogeneous mixture of fuel vapors and air. In order to prevent a flame front from propagating into the circulation system the 6.4 cm diameter pipes were plugged with 10 cm of red foam at the inlet to the tank. The circulation system was modified extensively when repairs became necessary about midway through the testing. The modified system was basically the same except that the foam flame arrestor in the 7.4 cm diameter pipes was replaced with a 5 cm ball valve to positively isolate the circulation system from the tank during the ballistic tests. Also part of the ducting was redesigned and flexible hose replaced previous hard plumbed ducting. See Figure No. 6.

### 3. PROJECTILES TESTED

There were two different projectiles tested during the duration of the program. These were the 23 mm HEI (High Explosive Incendiary) and the 50 caliber API (Armor Piercing Incendiary). The ~~50-caliber~~ API was a standard U.S. domestic projectile 12.7 mm in diameter. The projectiles were tested without down loading the rounds which resulted in nominal projectile velocities of 990 meters/second for the 23 mm HEI and 848 meters/second for the 50 caliber API. The projectile velocities were not measured for these tests but are projected from a large data base from previous firings.

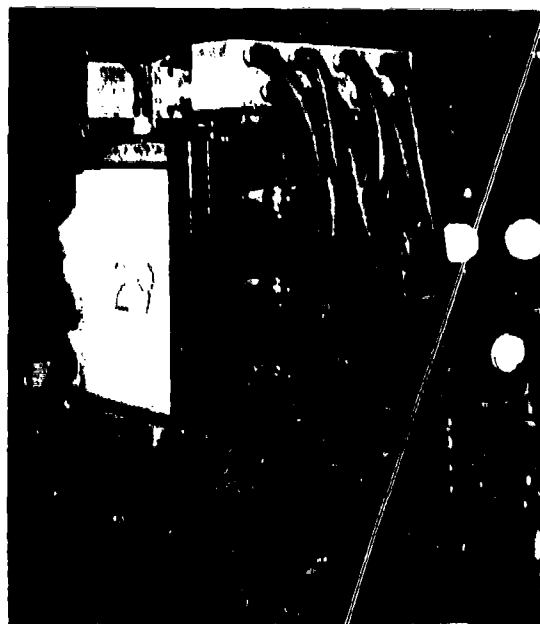


Figure 6. Modified Circulation System

The specimen was modified slightly when impacted with the 50 caliber API. A 4.76mm aluminum plate (approximately 15 cm square) was taped to the front panel. The API projectile would then penetrate a total of 6.53mm of aluminum which is more than adequate to activate the incendiary. This was determined from data presented in AFML-TR-68-223.

The 23mm HEI is a Soviet built projectile which contains 171 grains of explosive/incendiary mix. The fuze is the MG25 and the projectile is an Anti Aircraft Artillery (AAA) type. The MG25 fuze will provide a nominal 20 cm delay between the front tank wall and the detonation point. This was evident when examining the solid packed foam configuration which provided an excellent witness as to detonation point. There have been several hundred tests performed with the 23mm HEI projectile at the AFFDL/ASRF and the reliability of the 20 cm delay at muzzle velocity has been well established.

#### 4. ULLAGE SAMPLING SYSTEMS

The entire test program was dependent upon the ability to obtain and monitor the fuel/air ratio in the specimen so that a stoichiometric fuel/air ratio could be obtained. Due to its basic simplicity and need for no special instrumentation or equipment, it was decided to use a technique commonly referred to as a "bomb-sample" system. Basically the system consisted of a small pressure vessel approximately 262 milli-liters in volume into which ullage gases were drawn and then ignited with the peak overpressure being used to measure combustibility. The ullage sampling system was physically located

on the top of the TWS and all functions of the ullage sampling system were controlled remotely. These included solenoid operated valves at both the inlet and outlet of the sampler, a high energy spark ignitor which fires an automotive spark plug in the sampler, and other solenoid operated valves controlling the source of the sample.

The system was modified twice so that three different systems were used during the program. The three different systems are depicted in Figure No.'s 7 and 8. System 1 sampled from a single point in the circulation system. The tank was pressurized to 3.5 K Pa above atmospheric pressure in order for the ullage mixture to flow through the sampler. When a sample was taken, both inlet and outlet valves were opened and the ullage gases were allowed to flow through the sampler until a volume of gas equal to five times the volume of the ullage sampler (i.e. 1.31 liters) passed through (the flow rate was established using a rotometer during initial checkout). It was assumed that the flow through of 1.31 liters of gas would thoroughly purge the sampler of all gases present initially. After adequate flow through was obtained, the inlet valve was closed and the outlet valve was left open long enough for the sampler to be vented down to atmospheric pressure (all samples were tested at atmospheric pressure). Once the sampler was isolated (i.e. inlet and outlet valves closed) the spark ignition source was fired and the peak combustion overpressure was measured from an oscillograph recording of sampler pressure. The entire process required approximately three minutes to complete.

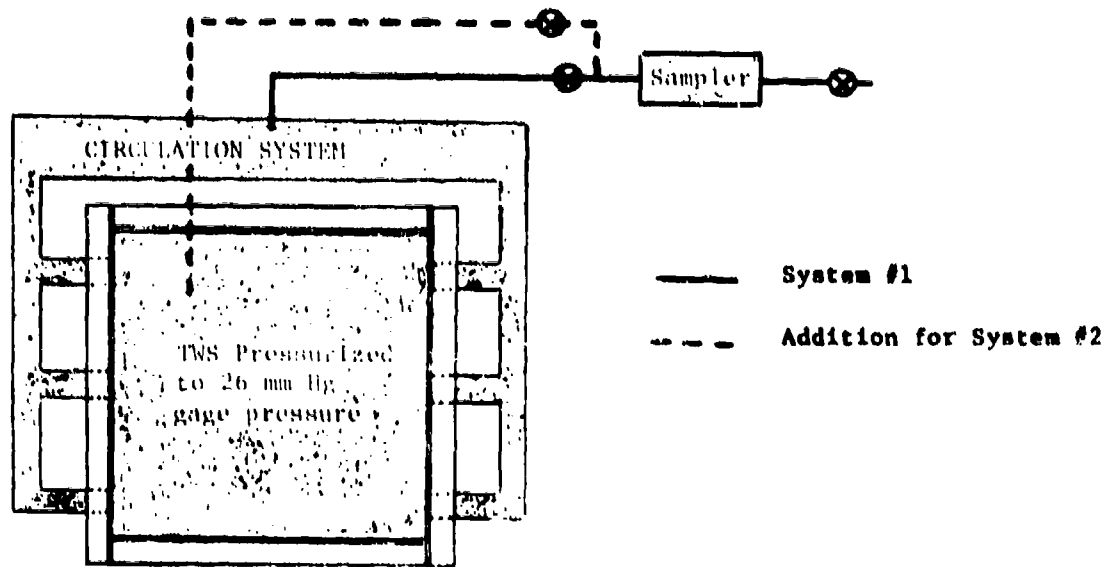


Figure 7. Ullage Sampling System No. 1 and 2

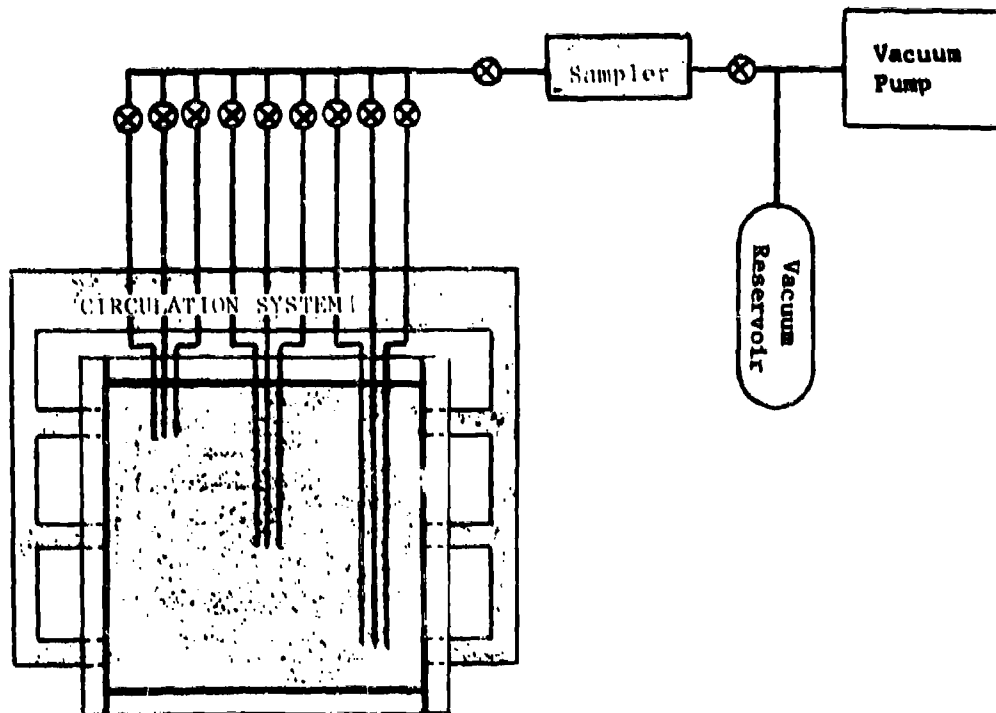


Figure 8. Ullage Sampling System No. 3



The measured ullage sampler overpressures were a function of the fuel/air ratio. The highest overpressures occur at a fuel/air ratio which will be referred to as "optimum for combustion". The overpressures obtained from mixtures any leaner or richer would result in a lower overpressure. This "optimum for combustion" mixture is near stoichiometric but not exactly stoichiometric. For reasons of reaction kinetics this "optimum for combustion" mixture is slightly richer than stoichiometric. The procedure in these tests was to initially fuel the TWS with JP-4 at a low enough temperature to ensure that the mixture would be on the lean side. Then with ambient temperatures generally higher than 0°C, the fuel would warm up and the fuel/air ratio would slowly increase. As this occurred, the ullage sampler overpressures were monitored until they peaked out, signalling an "optimum for combustion" mixture. The projectile was then launched immediately.

System 2 consisted of a slight modification to System 1, so that the sample could be selected from either of two locations (the circulation system or the top center rear void in the foam). This modification was performed so as to provide additional data on the homogeneity of the fuel/air ratio throughout the tank.

System 3, Figure No. 8, has the capability to select samples from any of nine locations in the tank. The major difference between this system and previous ones is that the ullage sampler was evacuated to less than .4 K Pa absolute pressure and then filled with the fuel/air mixture from the tank via one of nine supply lines. The control of the entire system, including monitoring combustion overpressures, was

done via a digital data acquisition and control system. This system was composed of an HP 2100 mini-computer with associated analog-to-digital converters, relay outputs, and data logging devices. The system was programmed to scan up to all nine locations and print out the results in real time. The program description and listing is included in Appendix A. The speed at which samples could be taken was slower than expected due mainly to the restriction of flow through the very small orifice valves and to a lesser extent, the restriction in the small (1.59mm) diameter tubing. The small diameter tubing was used to keep the volume in the lines between the sampler and the TWS to a minimum (longest line was 0.7% of sample volume). The sizing of the valves in future experiments should be done so that the valves represent a small portion of the total restriction. It is felt that sampling speed can be raised to six or more per minute as opposed to the sampling speed of one every 45 seconds attained in this program.

#### 5. TEST SET-UP/PROCEDURES

The test specimen was installed in the Air Force Flight Dynamics Laboratory/Aircraft Survivability Research Facility (AFFDL/ASRF), Range No. 3. The TWS was situated in the middle of the floor on a stand which raised the TWS 61 cm off the floor. This was done in order for the center of the TWS to be at the same level as the weapon. The weapon was placed outside the facility approximately ten meters from the TWS. See Figure No. 9.

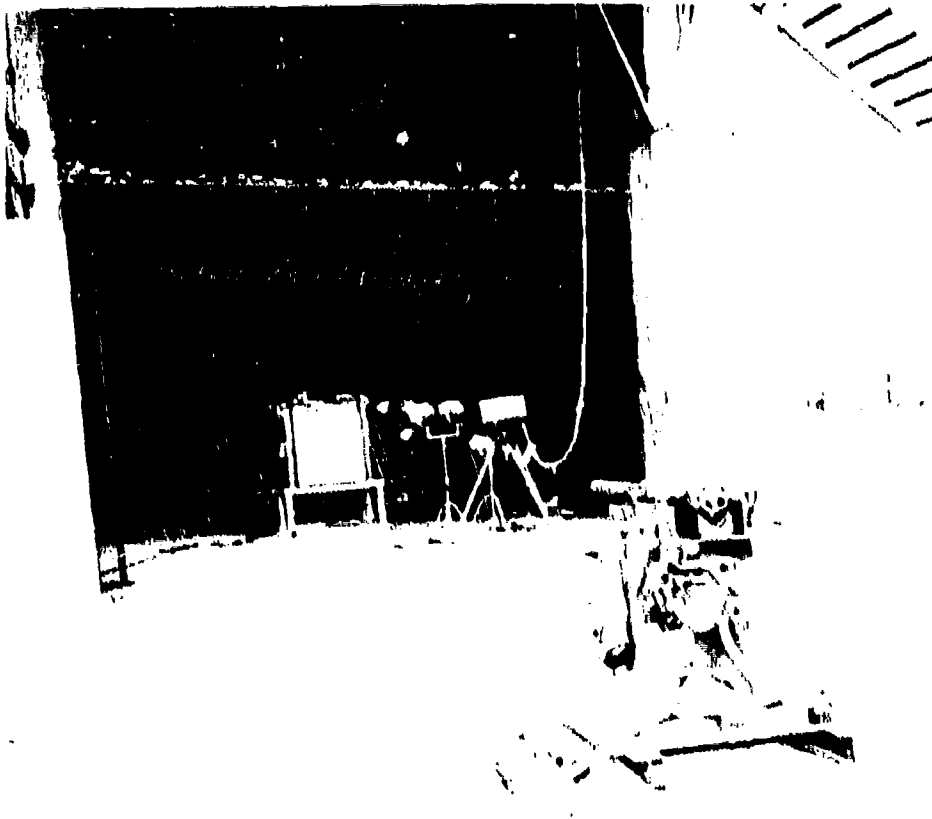


Figure 9. Overall Test Set-Up at AFFDL/ASRF Range No. 3

Figure No. 9 does not depict a steel protective deflector plate immediately in front of the TWS. This deflector plate was incorporated into the test set-up at a later time. The weapon and tank were oriented to produce an impact obliquity of  $0^\circ$  (i.e. perpendicular).

Two 16mm motion picture cameras were used to record the events on both the front and rear aluminum walls of the TWS. These cameras used color film and were operated at 250 frames per second. There were four 500 watt lights used to illuminate each wall.

The procedures followed for each test which required a fuel/air mixture were as follows:

1. Fill and drain the TWS with JP-4 conditioned to a temperature range of  $-18^\circ\text{C}$  to  $7^\circ\text{C}$  depending on ambient temperature.
2. Open isolation valves on circulation system where applicable.
3. Start fans in circulation system.
4. Pressurize the TWS to 3.5 K Pa if applicable.
5. Analyze ullage samples until an "optimum for combustion" fuel/air ratio is reached.
6. Close isolation valves on circulation system if applicable.
7. Fire weapon.

This procedure varied slightly for some of the tests. For example, Tests No. 1 through 5 were done without foam and did not incorporate the circulation system. Test No. 4 was performed with JP-4 fuel but only approximately 20 liters of fuel was in the TWS. For Test No. 6, foam was used but the specimen was filled and drained with JP-5 (high flash point hydrocarbon) so that the foam could be wetted without producing an explosive mixture. For Tests No. 25 through No. 30 the

TWS was not pressurized since it was not needed for ullage sample system operation. These test-to-test particulars are addressed in detail in Section III.

The tests with blue foam and the Astrocoated foam went through a special procedure prior to the standard ones listed here. It was determined in specific tests by Mr. T. O. Reed (ASD/ENFEF) that blue foam, when immersed in fuel, loses approximately 43% of its tensile strength in a very short period of time. These test data are presented in Appendix D. These data indicate that the loss in tensile strength occurs in approximately 15 minutes after immersion in the fuel. Due to this high loss in tensile strength when immersed in fuel, it was felt that the polyether foam should be tested under conditions which would ensure that the loss in tensile strength had occurred prior to projectile impact. There were two procedures used to ensure this loss in tensile strength. These were: (1) the TWS was filled with JP-4 at approximately 38°C and allowed to set for one hour prior to the standard fueling procedure, (2) the TWS was filled with JP-4 at ambient temperature and allowed to set overnight and tested the following morning. Astrocoated foam was created in the same manner because the coating, "Astrocoat" is a polyether urethane. The exact method used for each test with the polyether foams or the Astrocoated foam is detailed in the results summary of this report, Section III.4.

## SECTION 111

## RESULTS

## 1. BASELINE TESTS

The object of the baseline tests was to obtain an adequate understanding of the measured dynamic pressures resulting from the detonation of the 23 mm HEI projectile inside the TWS and to perform an undefended test (i.e. no foam, with stoichiometric mixture) with a 50 cal. API and a 23 mm HEI. The two undefended tests were done in order to underscore the need for fuel tank inerting. The tests No. 1 - 6, 21, 24 fall under the baseline category.

Test No. 1 through 4 were performed with 7075-T6 aluminum front and rear panels. These panels fractured very badly due to the properties of the 7075-T6 and therefore the material for the front and rear panels was changed to 2024-T3. The results of tests No. 1 through 4 will not be discussed in any detail since they were repeated with 2024-T3 aluminum panels. During these four tests the instrumentation was debugged and it was felt that the combustion overpressures could be easily distinguished from the blast shock wave type pressures. Figure No. 10 illustrates the difference in the response of the two materials. Both panels shown were from the rear of the TWS and had been subjected to a 23 mm HEI detonation inside the TWS with air only (no foam or fuel). The panel on the left was from Test No. 5 (2024-T3) and the panel on the right was from Test No. 3 (7075-T6).

The change to 2024-T3 aluminum panels prompted a repeat of the baseline tests due to the greatly increased tolerance of 2024-T3 to

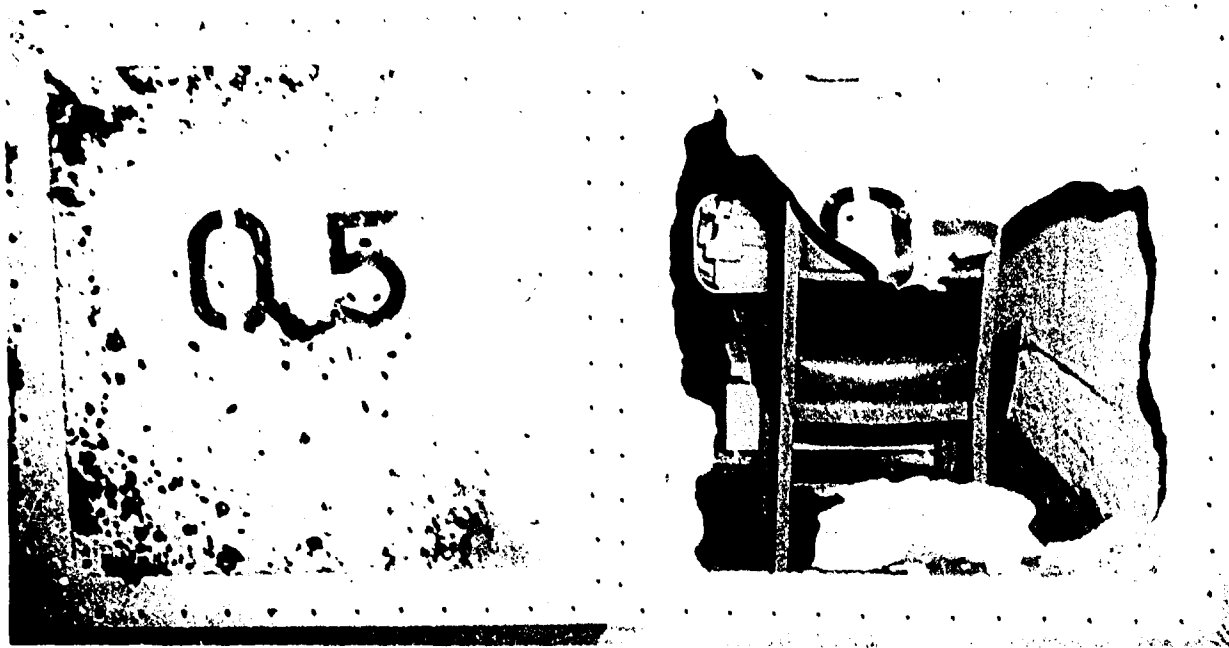


Figure 10. Comparison of 2024-T3 (Test No. 5, left) and 7075-T6 (Test No. 3, right) Response to the 23 mm HEI

ballistic damage. Test No. 5 was the first test run with 2024-T3 panels. It was performed to see what pressure histories were obtained with no foam and no fuel vapors present when a 23 HEI is detonated in the TWS. Figure No. 11 is a graph of pressure versus time for Test No. 5 and depicts a series of pressure oscillations which are attributed to the blast shock wave reverberating inside the tank. Also evident is an abrupt increase in quasi-static pressure at impact which then decays through venting. With this data superimposed upon a gentle (by comparison) pressure rise due to the combustion overpressure, it was assumed that the two different frequency signals could be easily distinguished, during the baseline tests with fuel.

Test No. 6 was performed next to answer the question of what the presence of internal foam does to the measured overpressures due solely to 23 HEI detonation. Figure No. 12 is a graph of pressure versus time for this test and depicts a short pressure excursion followed by the decay of the initial 5 K Pa static pressure. As compared to the pressure history with no foam in the tank it can be seen that the foam greatly attenuates blast pressures. These data meant that there should be no trouble whatsoever recording combustion overpressures during the foam tests.

Tests No. 21 and 24 are baseline tests which consisted of impacting a tank containing an "optimum for combustion" fuel/air ratio with 50 cal. API and a 23mm HEI. The TWS for both tests did not contain any foam, so for all practical purposes, the tanks were fuel air bombs.



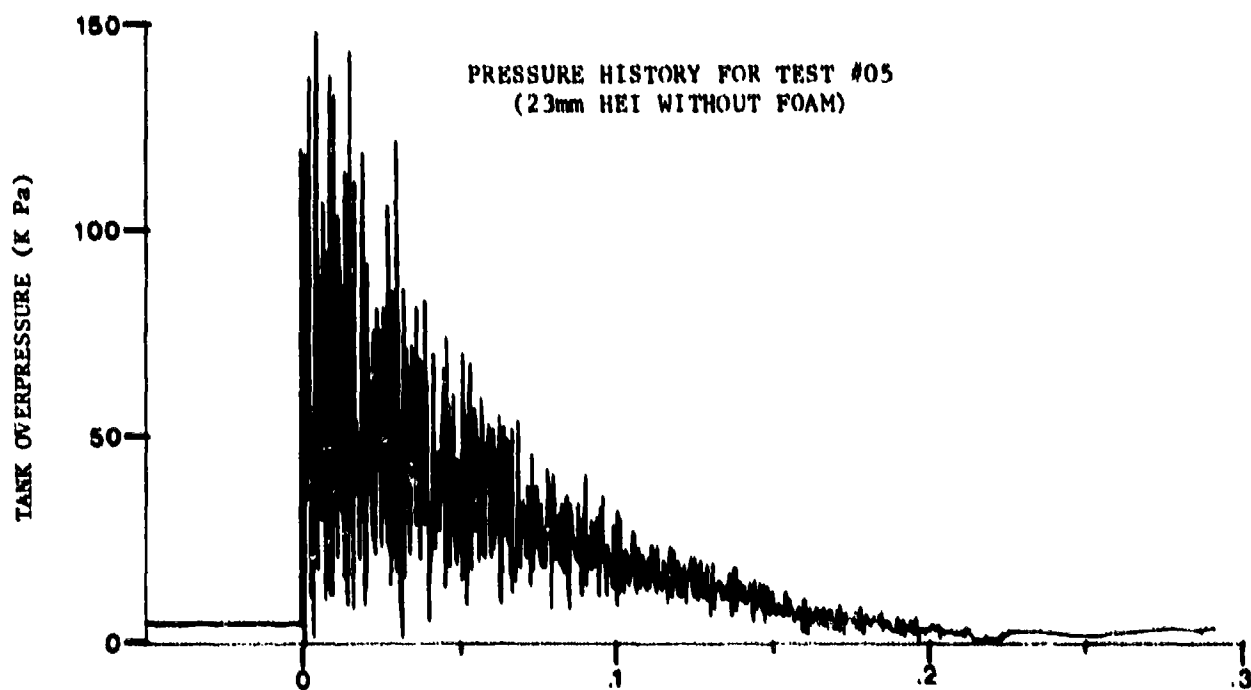


Figure 11. Pressure History for Test No. 5 (23 mm HEI with no Foam)

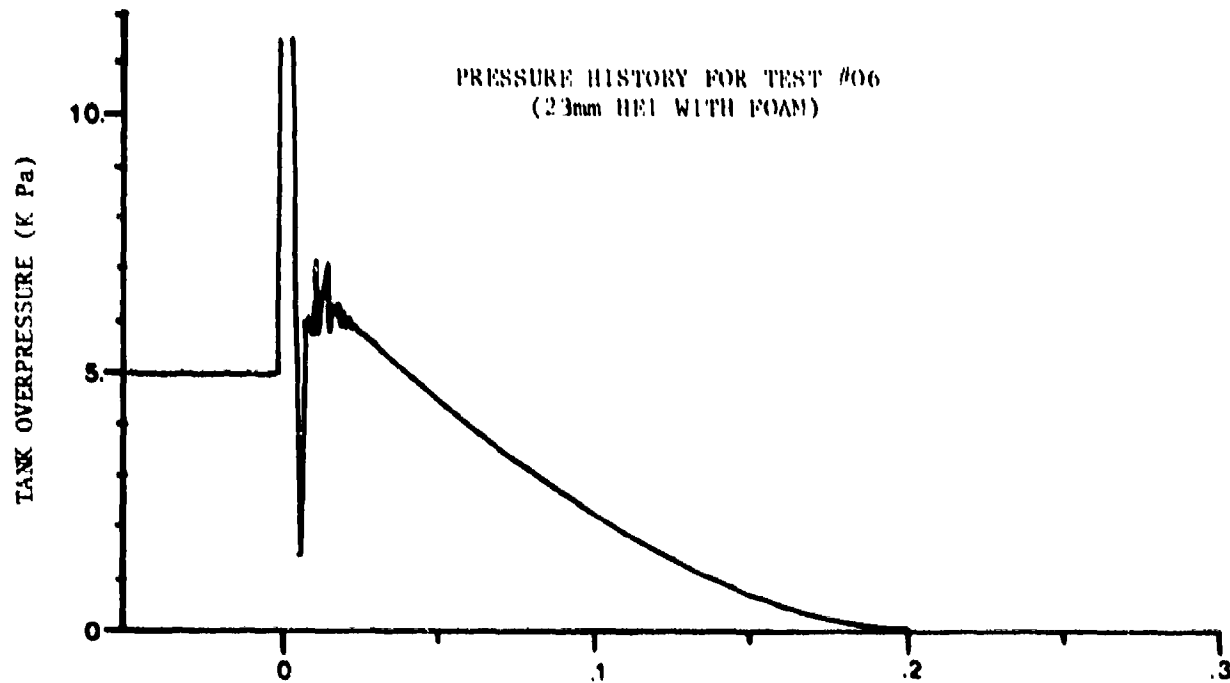


Figure 12. Pressure History for Test No. 6 (23 mm HEI with Foam)

Figure No. 13 is a composite graph of pressure versus time for test No. 21 and 24. The peak pressures for both tests were approximately the same at 330 and 340 K Pa for Tests No. 21 and 24 respectively. Both curves exhibit a very rapid drop in pressure after the peak which is attributed to the abrupt failure of the rear wall in both cases. However, the striking difference between the two pressure histories is in the rise times. The API projectile produced a rise time of 32 milliseconds while the HEI projectile produced a rise time of approximately 6 milliseconds. The extremely fast rise time with the HEI is attributed to the size of the ignition source as compared to an API projectile. The larger the ignition source, the less time required for the total combustion process. Figure No. 14 indicates the severity of the damage resulting from these tests. As can be seen, almost the entire rear wall of the tank was blown out. The results depicted in Figure No. 14 are typical for both Test No. 21 and 24.

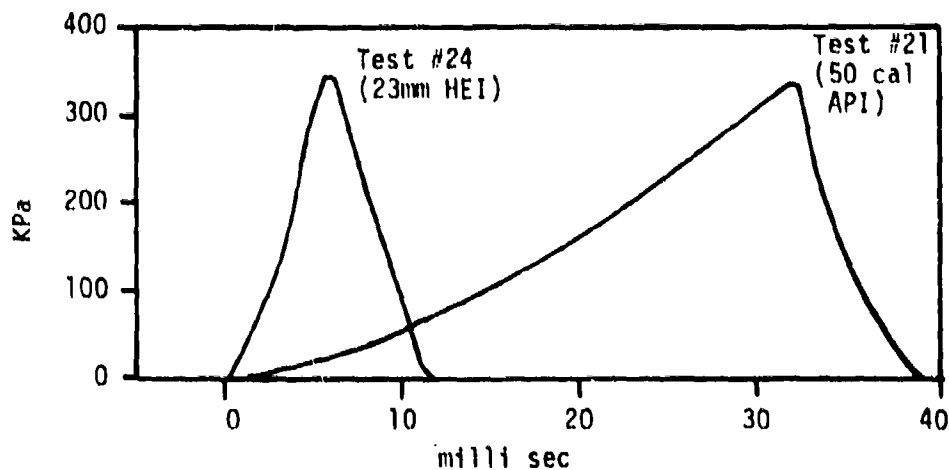


Figure 13. Comparison of Overpressure Histories (50 cal. API and 23 mm HEI, Stoichiometric Mixture, no Foam)

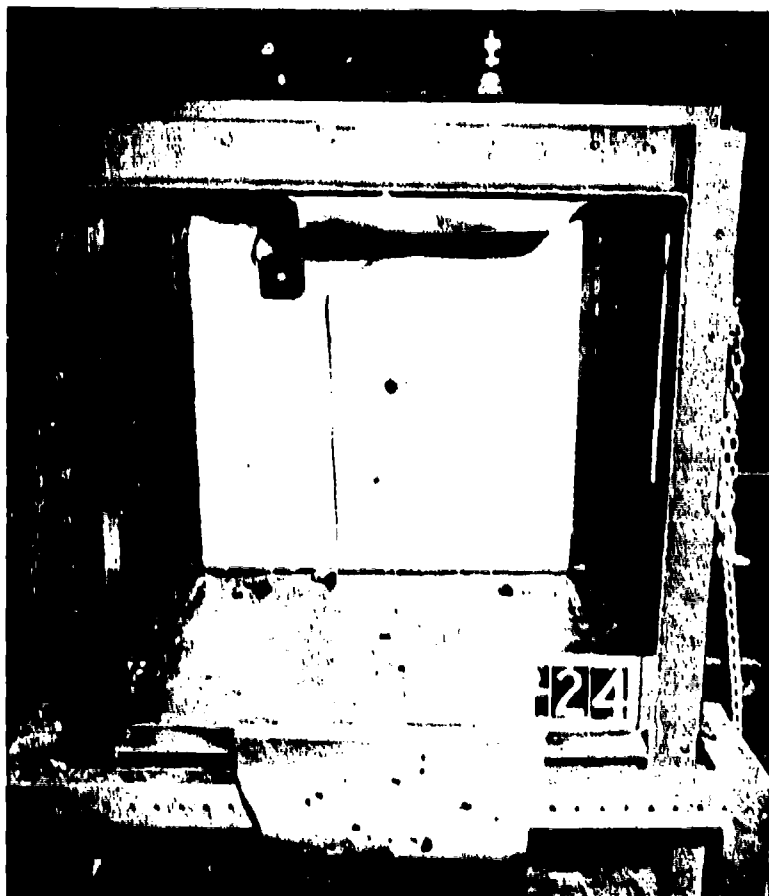


Figure 14. Test No. 24, Rear Wall Failure

## 2. COMPARISON OF FOAMS

As was stated earlier the objective of this program was to evaluate the ballistic performance of the new polyether urethane (blue) foam against the polyester urethane foams (red and yellow). The results of the foam tests will be included in this section along with the results of the Explosafe tests.

The criteria used for evaluation of the explosion suppression materials include combustion overpressure and physical damage to the materials. The combustion overpressure data will be used as the primary measure of performance and the mechanical/physical damage will be secondary and serve to back-up the overpressure data. The motion picture coverage will also be used for a rough cross check of results since any combustion overpressures occurring in the TWS will be easily seen with the two cameras.

The description of the results will be broken down into the following series; fully packed foam, voided (egg crate) foam, Astro-coated red foam, and Explosafe. A summary of the results is presented in Section III.4. Test Results Summary. Listed is a pressure decay time which can be used to identify minimal combustion inside the TWS that does not produce a measureable overpressure.

### a. Fully Packed Foam

There were four tests performed in this series; Test No. 11 (red foam), Test No. 16 (yellow foam), Test No. 17 (fine pore blue foam), and Test No. 18 (coarse pore blue foam). Each of these tests

was performed only with the 23mm HEI projectile (50 cal. API not used for this series). The results for all four tests were virtually identical. Figure No. 15 is a graph of pressure versus time for this series of tests. The pressure histories for each of the tests fell within the band indicated. The mechanical/physical damage to the foam for each test was also virtually identical. There was no noticeable difference between the polyether and the polyester foams in the size of the pocket produced by the 23mm HEI detonation. Figure No. 16 and 17 are photographs of the different pockets. The volume of foam wiped out was approximately 1.1 liters. Figure No. 18 and 19 compare the damage to the exit panels for the tests performed in this series.

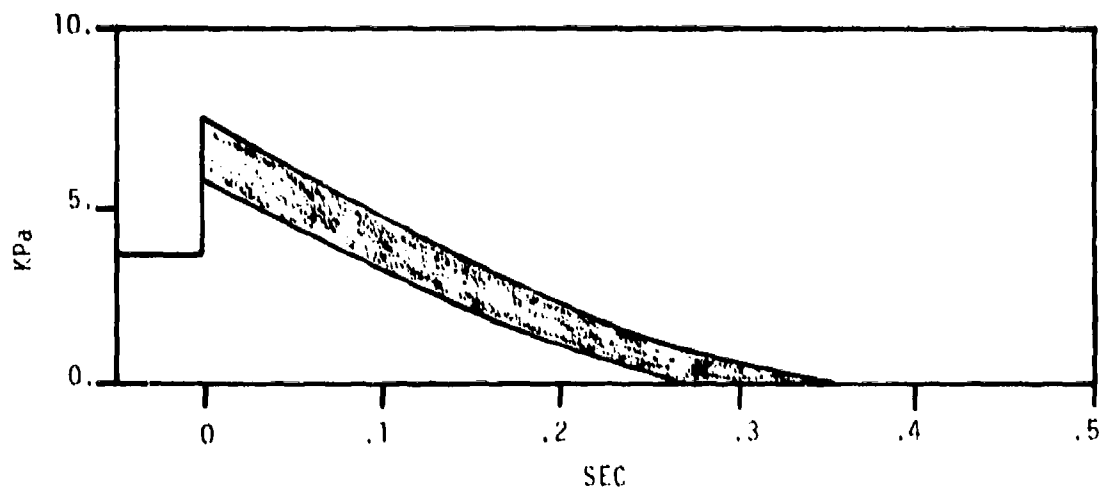


Figure 15. Overpressure Histories for Fully Packed Foam (23 mm HEI)

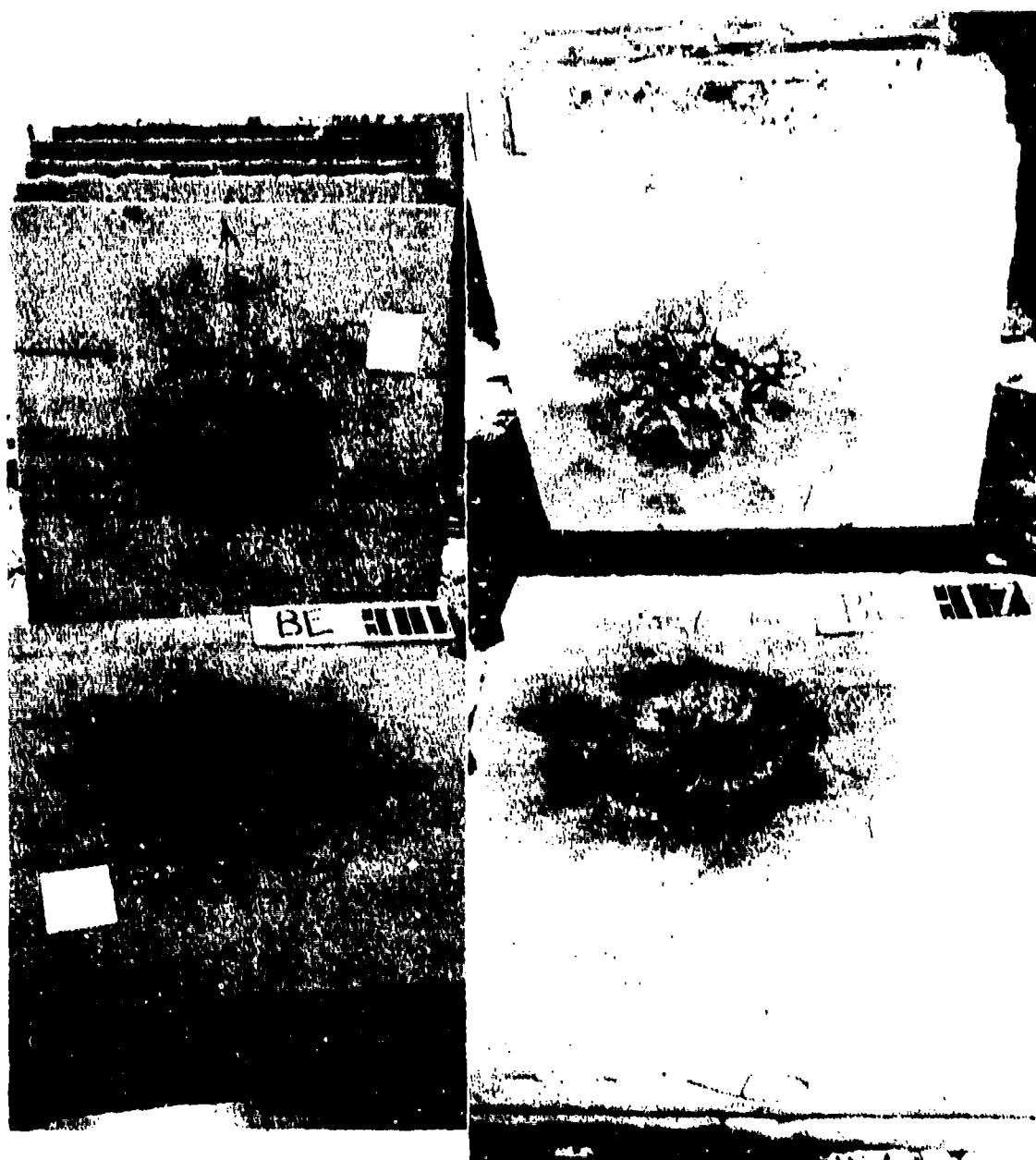


Figure 16. Comparison of Blast Pockets, Red Foam (Test No. 11, Left), Fine Blue Foam (Test No. 17, Right)

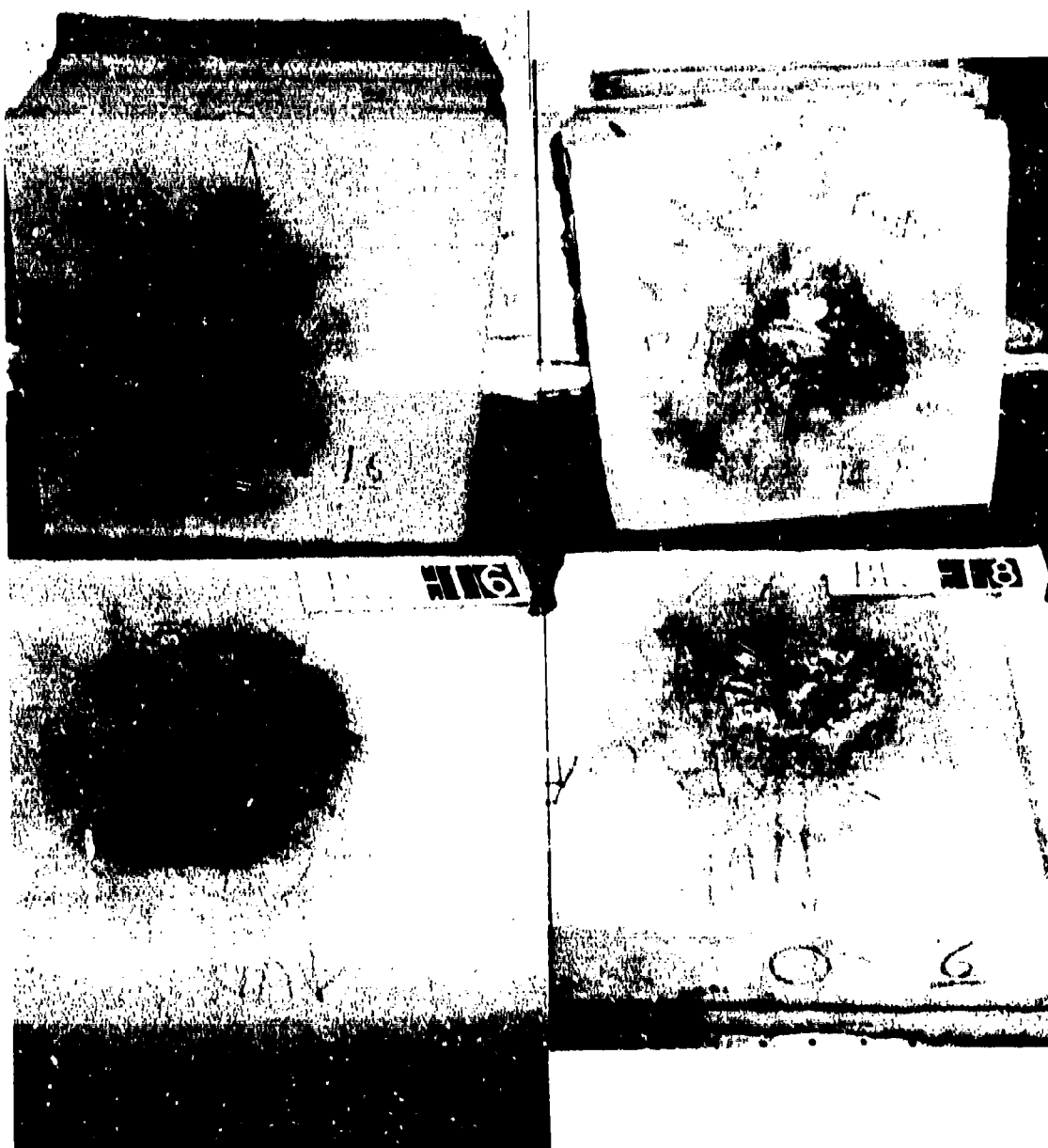


Figure 17. Comparison of Blast Pockets, Yellow Foam (Test No. 16, left), Coarse Blue Foam (Test No. 18, right)

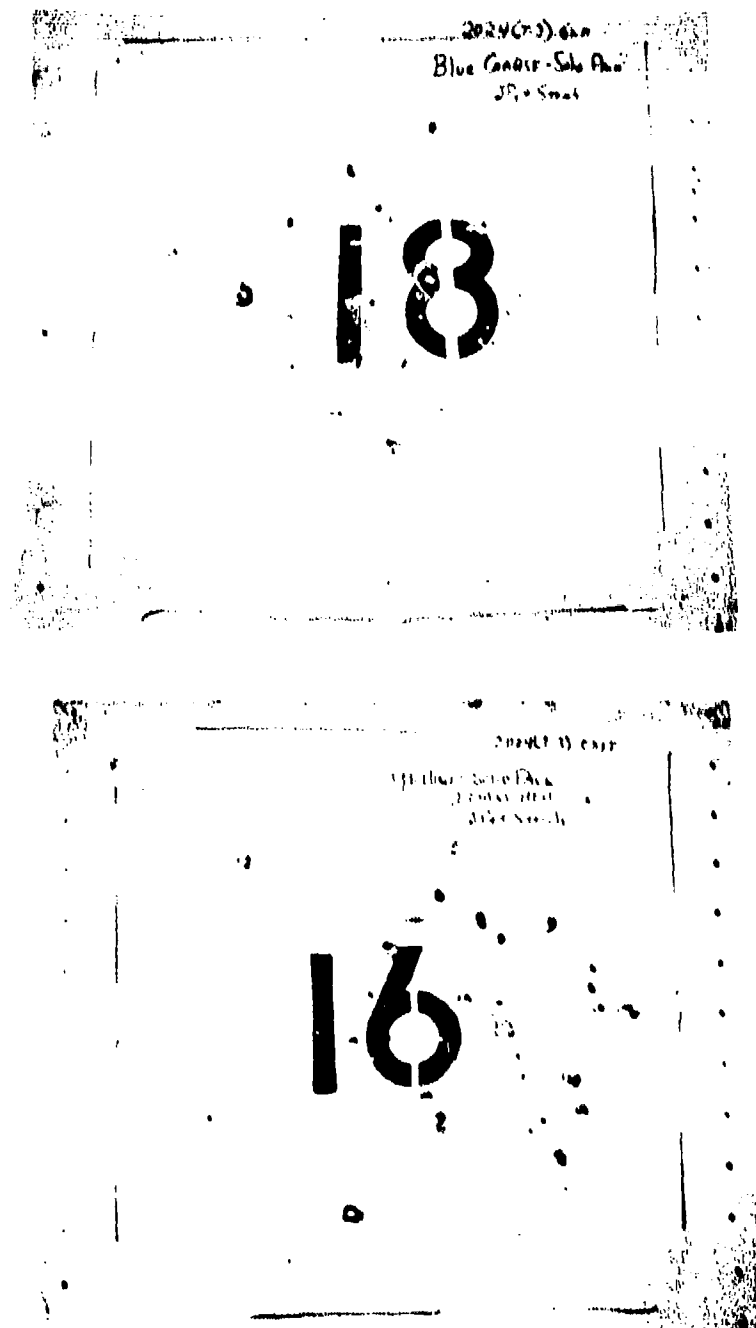


Figure 18. Comparison of Exit Panels, Coarse Blue Foam (Top, Test No. 18) and Yellow Foam (Bottom, Test No. 16), Fully Packed Configuration



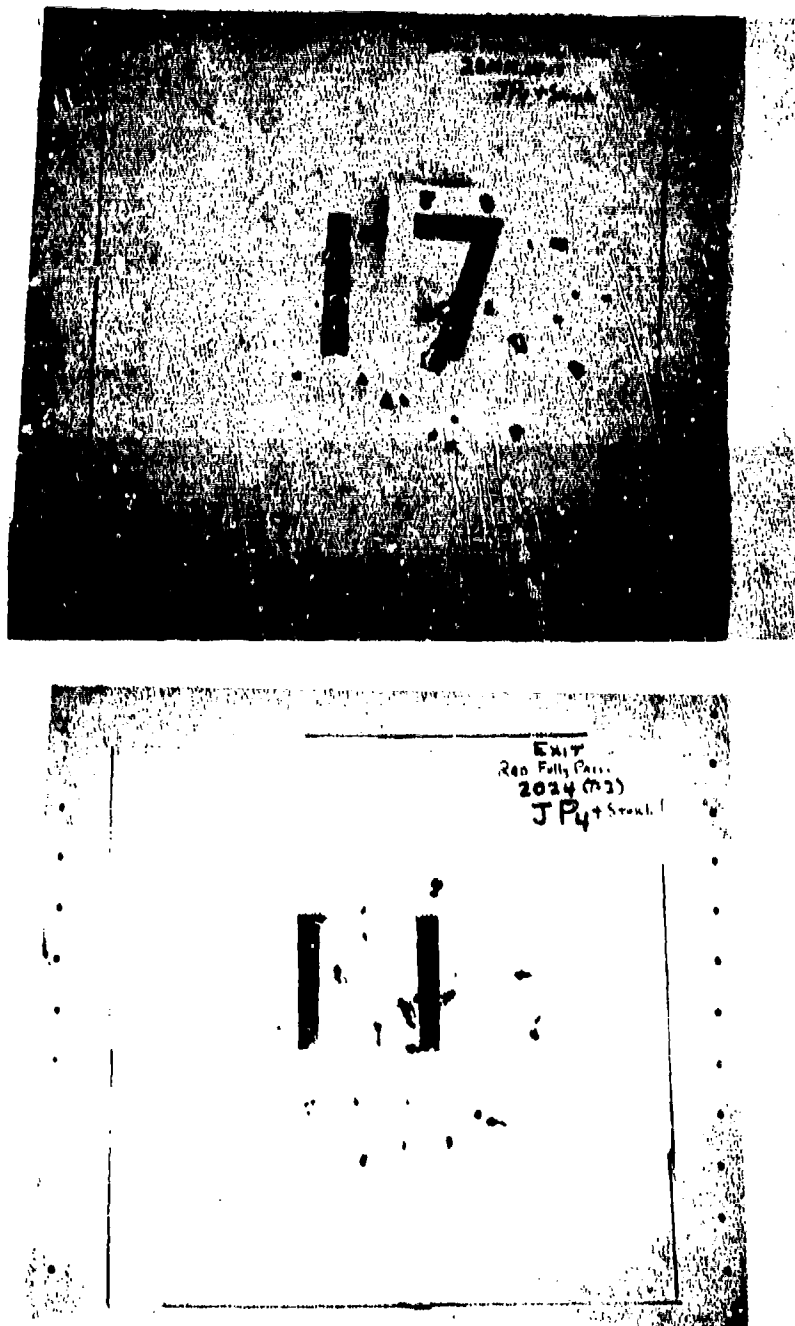


Figure 19. Comparison of Exit Panels, Fine Blue Foam (Top, Test No. 17) and Red Foam (Bottom, Test No. 11), Fully Packed Configuration

b. Voided Foam

There were nine tests performed in this series; Tests No. 7 and 8 (red foam), Tests No. 9 and 10 (yellow foam), Tests No. 12, 13 and 15 (fine pore blue foam), and Tests No. 14 and 19 (coarse pore blue foam). Each type of foam was tested with both the 50 cal. API and the 23mm HEI. Test No. 13 is a repeat of Test No. 12 due to the failure of the incendiary in the 50 cal. API to activate properly on Test No. 12 (activated near the rear wall). Some variation in results were encountered. However, in no case did the combustion overpressure exceed the flame tube test data presented in Appendix B. These data were gathered using the test techniques described in MIL-B-83054A.

The results will be discussed for each projectile independently. The 50 cal. API projectile generally produced very little, if any, combustion overpressure with one exception. That exception was for Test No. 9 with the yellow foam when a 27.8 K Pa overpressure was recorded. This overpressure is in the range of what can be expected as the data in Appendix B show.

The physical damage to the foam for this test consisted of singeing on the surface of the foam voids caused by the combustion of the fuel/air mixture. The singeing was not present on any of the other eight tests in this series. The motion picture data corroborates the pressure data, showing smoke being forced out of the entrance and exit holes for an extended period of time.

It should be noted that on Test No. 12 (improper API functioning), the fine pore blue foam actually burned in the tank (smoldering) for approximately 90 seconds. This produced a burned out pocket shown in Figure 20.



Figure 20. Test No. 12, Burned Out Pocket

This reaction, whereby the foam smolders is usually confined to tests with dry foam but there have been other occurrences of red foam actually smoldering after ballistic impact.

The results with the 23mm HEI were very similar to those obtained with the 50 cal. API. The 23mm HEI did not produce any significant overpressures. Some overpressure was recorded for each of the tests and is summed up in a pressure history curve presented in Figure 21.

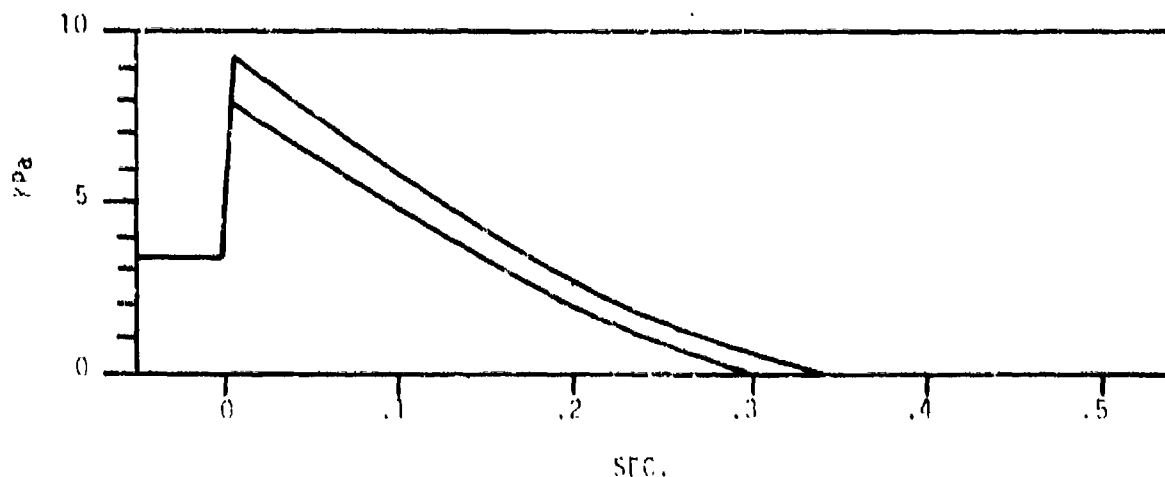


Figure 21. Overpressure Histories for Voided Foam (23 mm HEI)

The combustion overpressure data from each of the four tests with 23mm HEI fell within the band shown. Note the faster decay time for this data as opposed to the API which is attributed to the increased venting via the multiple fragment holes in the rear panel. Figures No. 22 and 23 compare the same to the exit panels for tests performed with 23mm HEI in this series.

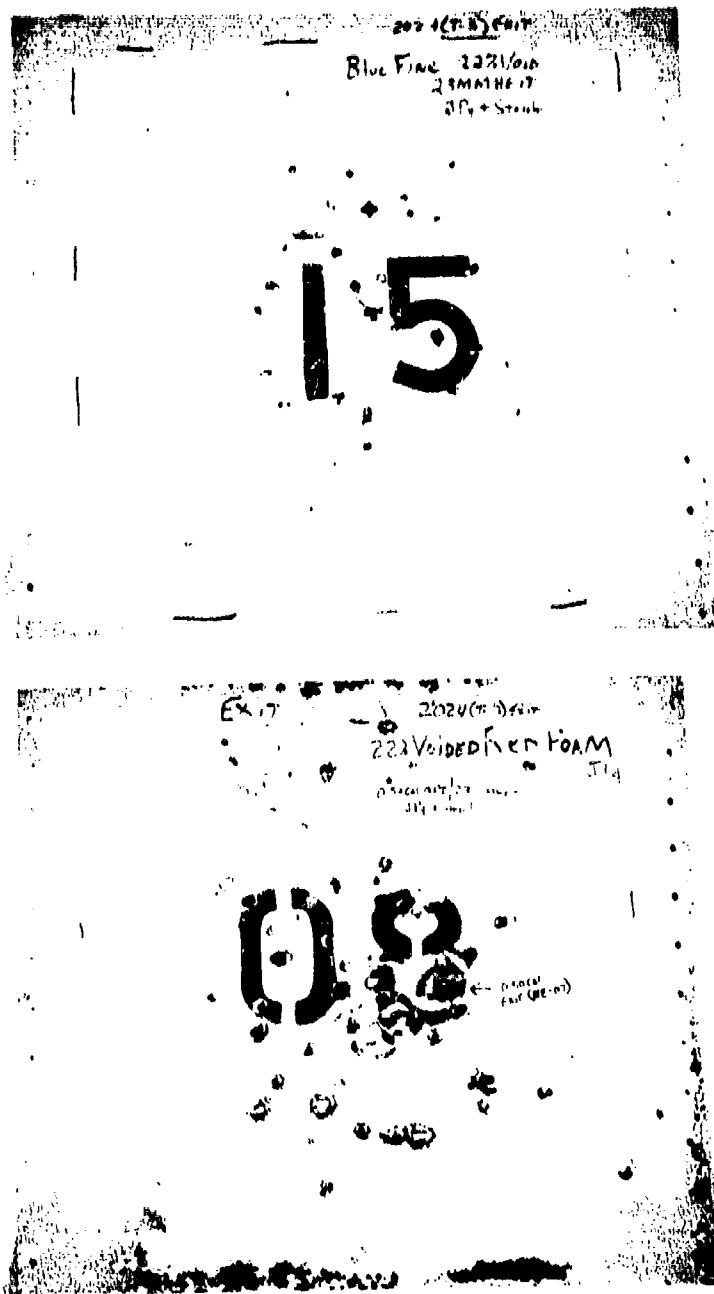


Figure 22. Comparison of Exit Panels, Fine Blue Foam (Top, Test No. 15) and Red Foam (Bottom, Test No. 8), Egg Crate Voiding Configuration

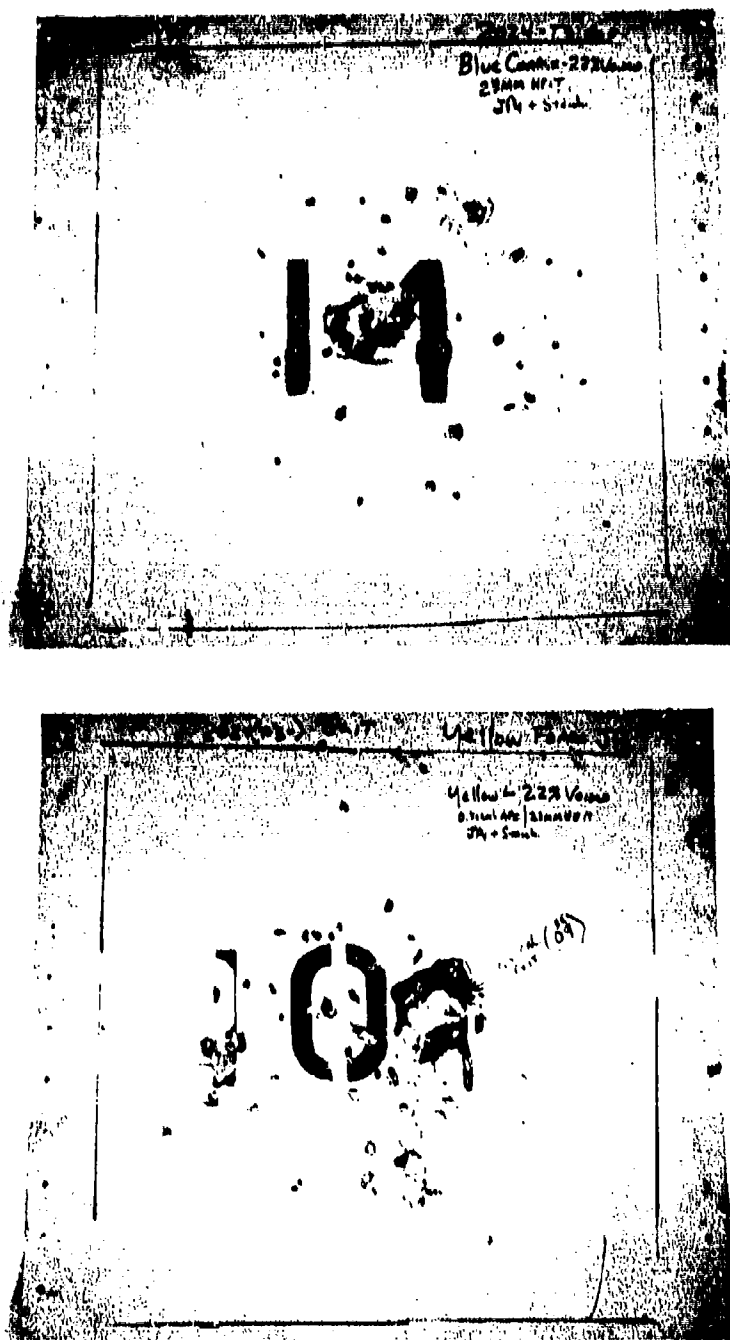


Figure 23. Comparison of Exit Panels, Coarse Blue Foam (Top, Test No. 14) and Yellow Foam (Bottom, Test No. 10), Egg Crate Voiding Configuration

All of the photographic data corroborates the pressure data which indicates no significant combustion overpressures. The initial increase in pressure shown in Figure No. 21 is attributed to blast products or to limited combustion of fuel vapor in the immediate vicinity of the blast. There was definitely no flame propagation inside the TWS as a result of the 23mm HEI impacts.

There was one factor affecting the combustion overpressures in this series that should be noted. This series of tests was performed with the initial circulation system. The initial circulation system, which was actually part of the TWS, had a volume equal to 20% of the basic TWS. But, there was no combustion in the circulation system due to foam plugs at the entrance and exit of each tube. Therefore, the circulation system served as a volume into which any overpressures in the tank could relieve and thereby effectively lower the peak pressure.

c. Astrocoated Red Foam

There were two tests performed in this series; Test No. 25 (50 cal. API) and Test No. 26 (23mm HEI). The foam configuration for these tests was the "egg crate" voiding. The basic TWS was changed slightly for this series and all later tests. The circulation manifold was isolated from the main tank beginning with this series of tests as is explained in Section II of this report.

The results for these two tests were slightly different from the previous voided foam tests. The amount of physical/mechanical damage

from the 23mm HEI was unchanged, but the overpressures for both projectiles was higher than the average for the voided foam series. The pressure history for these tests is presented in Figure No. 24. Figure No. 25 is a photograph showing the damage to the exit panel for the two tests performed in this series.

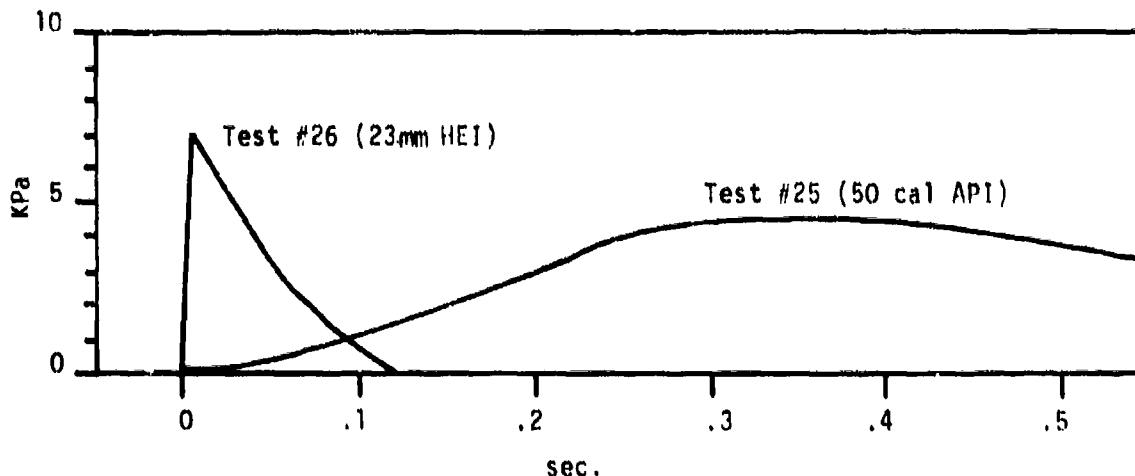


Figure 24. Overpressure Histories for Astrocoated Foam

These overpressures are slightly higher and can be attributed, at least in part, to the isolation of the circulation system which permitted some pressure relief on previous tests. These two tests were performed in succession and the foam was not changed between the 50 cal. API impact and the 23mm HEI. After the 23mm HEI test the tank was opened and the foam examined. Singeing of the foam was observed on two of the rear pieces of foam indicating combustion had taken place. The movie data also corroborated the overpressure data for the 50 cal. API test by indicating sustained venting from the exit holes. The pressure and movie data indicate that the foam singeing occurred with 50 cal. API and not with the 23mm HEI.





Figure 25. Exit Panel, Astrocoated Red Foam, Egg Crate Voiding Configuration (Test No. 26)

## d. Explosafe

There were three tests performed in this series; Test No. 20 and 27 (50 cal. API) and Test No. 28 (23mm HEI). Each test was conducted with the Explosafe "solid packed" in the TWS and the same set of Explosafe was used for all three tests. The results for Test No. 20 will be treated separately due to the unusual results. Test No. 20 was conducted using the TWS which incorporated the original circulation system. This circulation system could not be isolated from the TWS and therefore used small pieces of red foam to prevent flames from entering the circulation system. On this particular test the flame front propagated into the circulation system and produced an explosion which caused significant damage to the circulation system. The fact that the flame front traveled to the side of the tank indicates that combustion occurred throughout most of the tank. The pressure data is of questionable value due to the explosion in the manifold and therefore very little could be deduced from this test as to performance of the metal arrestor.

The test of the metal arrestor with 50 cal. API was repeated after the TWS was repaired and the modified circulation system installed. Test No. 27 was the repeat of Test No. 20 and resulted in no measurable overpressures. This indicates that there was no significant combustion in the TWS, which is contrary to the results of Test No. 20. The mechanical damage to the metal arrestor from the 50 cal. API consisted of a hole completely through the metal arrestor ranging from 2 to 4 cm in diameter. Test No. 28 was performed with the 23mm HEI but

unfortunately no overpressure data was recorded due to a magnetic tape transport malfunction. But, from movie data, it was determined that there were no significant combustion overpressures due to the obvious lack of any venting gases. The mechanical damage to the metal arrestor was significantly worse than observed with the foam. Figure No. 26 is a photograph showing the large cavity in the Explosafe from the HEI blast. Figure No. 27 is a photograph showing the damage to the exit panel for Test No. 27 and 28.

### 3. DRY FOAM TESTS

The combustion overpressure data for this overall program generally ran lower than predicted from flame tube data. The primary reason for the difference is that these tests were conducted using wet foam (holding JP-4) as opposed to dry foam in the flame tube tests. Wet foam is a better flame arrestor than dry foam.

Test No. 29 (50 cal. API) and Test No. 30 (23mm HEI) were performed to verify this phenomena if possible. For these tests JP-4 was pumped into the bottom of the tank only (approximately 40 liters) and the vapors



Figure 26. Blast Pocket In Explosive



Figure 27. Exit Panel, Solid Packed Explosafe (Test No. 28)

dispersed via the circulation system. Test No. 29 and 30 both resulted in a significant increase in the combustion overpressure. Both tests were performed with coarse blue foam in the "egg crate" voiding configuration and there was singeing of the foam throughout the tank which indicated combustion occurred in a large majority of the TWS. Figure No. 28 shows a pressure history for both tests performed in this series. Figure No. 29 is a photograph showing the damage to the exit panel for Test No. 30, performed with the 23mm HEI.

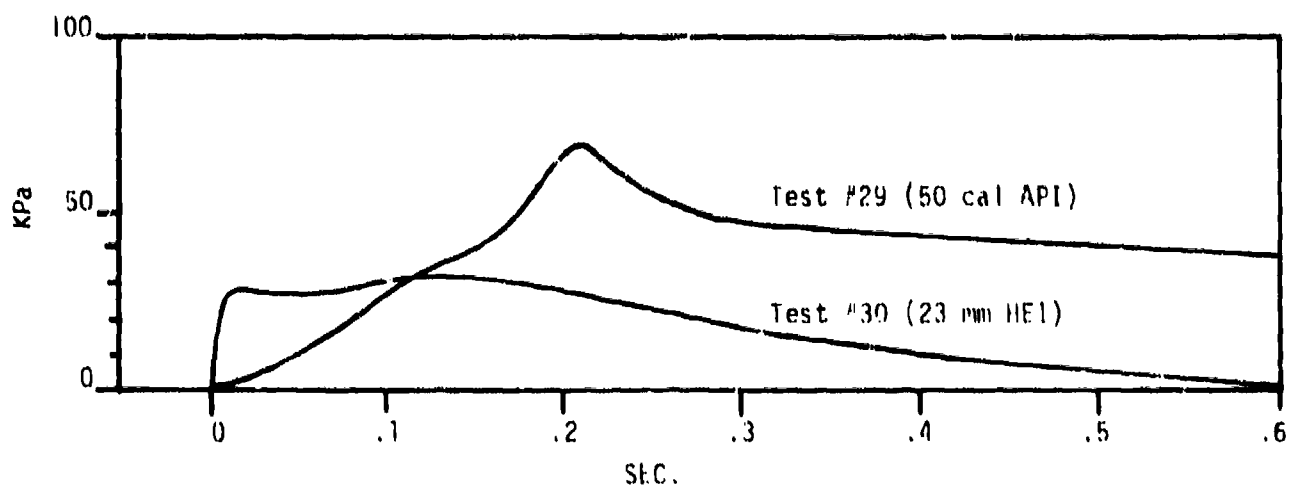


Figure 28. Overpressure Histories for Dry Foam



Figure 29. Exit Panel, Dry Foam, Coarse Blue Foam, Egg Crate  
Voiding Configuration (Test No. 30)

## 4. TEST RESULTS SUMMARY

Test No.	Threat	Foam Type	Voiding Config.	Fueling Proced.	Fuel/Air Ratio	Initial Tank Press. K Pa	Front/Rear Wall	TNS No.	Combustion		Comments
									Over Press. K Pa	Decay Time sec.	
01	23 HEI	none	N/A	none	N/A	20.6	7075-T6	1	N/A	N/A	
02	23 HEI	none	N/A	none	N/A	3.5	7075-T6	1	N/A	N/A	
03	23 HEI	none	N/A	none	N/A	3.5	7075-T6	1	N/A	N/A	
04	50 cal API	none	N/A	20 ltr JP-4	Optm.	3.5	7075-T6	1	280	-	.022 sec. rise time, complete failure of both walls
05	23 HEI	none	N/A	none	N/A	3.5	2024-T3	1	N/A	N/A	
06	23 HEI	coarse blue	Egg-Crt Void	F/Drain JP-5	N/A	3.5	2024-T3	1	N/A	N/A	
21	50 cal API	none	N/A	12 ltr JP-4	Optm.	3.5	2024-T3	1	330	-	.032 sec. rise time, rear wall failure only
24	23 HEI	none	N/A	20 ltr JP-4	Optm.	0	2024-T3	1	340	-	.006 sec. rise time, rear wall failure only
11	23 HEI	red	Solid	F/Drain JP-4	Optm.	3.5	2024-T3	2	4.1	.35	
16	23 HEI	yel-low	Solid	F/Drain JP-4	Optm.	3.5	2024-T3	2	3.7	.30	
17	23 HEI	fine blue	Solid	F/Drain JP-4	Optm.	3.5	2024-T3	2	2.3	.27	overnight soak
18	23 HEI	coarse blue	Solid	F/Drain JP-4	Optm.	3.5	2024-T3	2	2.7	.38	1 hour soak @ 38°C

Baseline Tests

Fully Packed Foam



## 4. TEST RESULTS SUMMARY (Continued)

Test No.	Threat	Foam Type	Voiding Config.	Fueling Method	Fuel/Air Ratio	Initial Tank Press. K Pa	Front/Rear Wall	TMS No.	Combustion		Comments
									Over Press. K Pa	Decay Time sec.	
07	50 cal API	red	Egg-Crt Void	F/Drain JP-4	Optm.	3.5	2024-T3	2	0	.42	Tank not opened between tests,
08	23 HEI	red	Egg-Crt Void	F/Drain JP-4	Optm.	3.5	2024-T3	2	5.2	.3	Foam singeing present
09	50 cal API	yellow	Egg-Crt Void	F/Drain JP-4	Optm.	3.5	2024-T3	2	28	1.55	Tank not opened between tests No. 9 and 10
10	23 HEI	yellow	Egg-Crt Void	F/Drain JP-4	Optm.	3.5	2024-T3	2	5.4	.3	Tank not opened between tests No. 9 and 10
12	50 cal API	fine blue	Egg-Crt Void	F/Drain JP-4	Optm.	3.5	2024-T3	2	2.5	1.3	1 hr soak @ 38°C Pocket of foam burned at top rear, API didn't activate on front wall
13	50 cal API	fine blue	Egg-Crt Void	F/Drain JP-4	Optm.	3.5	2024-T3	2	0	.28	1 hour soak @ 38°C
14	23 HEI	coarse blue	Egg-Crt Void	F/Drain JP-4	Optm.	3.5	2024-T3	2	4.4	.34	1 hour soak @ 38°C
15	23 HEI	fine blue	Egg-Crt Void	F/Drain JP-4	Optm.	3.5	2024-T3	2	4.4	.34	overnight soak
19	50 cal API	coarse blue	Egg-Crt Void	F/Drain JP-4	Optm.	3.5	2024-T3	2	0	.49	1 hour soak @ 38°C
25	12.7 API	coated red	Egg-Crt Void	F/Drain JP-4	Optm.	0	2024-T3	2a	4.6	-	overnight soak Tank not opened between tests
26	23 HEI	coated red	Egg-Crt Void	F/Drain JP-4	Optm.	0	2024-T3	2a	7.2	-	overnight soak Singeing on rear pieces of foam

Voided Foam

Red Foam

## 4. TEST RESULTS SUMMARY (Concluded)

Test No.	Inert	Foam Type	Voiding Config.	Fueling Proced.	Fuel/Air Ratio	Initial		Front/Rear Wall	TWS No.	Combustion		Comments
						Tank Press. K Pa	Press. K Pa			Over Press. K Pa	Decay Time sec.	
20	50 cal API	Explo-safe	Solid	F/Drain JP-4	Optm.	3.5	-	2024-T3	2	-	-	Circulation manifold exploded
27	50 cal API	Explo-safe	Solid	F/Drain JP-4	Optm.	0	0	2024-T3	2a	0	N/A	Same material used as in Test No. 20
28	23 HEI	Explo-safe	Solid	F/Drain JP-4	Optm.	0	ND	2024-T3	2a	ND	ND	Same material used as in Test No. 20 & 27
29	50 cal API	coarse blue	Egg-Crt Void	40 ltr JP-4	Optm.	0	70	2024-T3	2a	70	-	Singeing throughout TWS
30	23 HEI	ccarse blue	Egg-Crt Void	40 ltr JP-4	Optm.	0	32	2024-T3	2a	32	-	Singeing throughout TWS, foam burned badly

Explosive

Dry Foam

#### SECTION IV

##### DISCUSSION OF RESULTS

The single most important aspect of these tests was controlling and monitoring the ullage fuel/air ratio in the TWS. The use of internal foam or metal arrester complicated this task. If no foam was used, as in some of the preliminary tests, the controlling of the mixture would be fairly easy. It was found that a simple small fan can be incorporated into the ullage space to effectively "mix up" the ullage to ensure a homogeneous fuel/air ratio. With the foam present in the tank, a fan inside will not effectively circulate the mixture due to the high restriction to flow which the foam presents. The system that was developed for this mixing effectively pulls gases out of one side of the tank and returns the gases in the opposite side of the tank resulting in the circulation of gases in a loop. It was felt that this circulation system does an extremely effective job at "mixing up" the ullage gases. This was proven with the nine point ullage sampling system on several tests. Before the circulation fans were started samples were taken which indicated large differences in the fuel/air ratio throughout the tank. Within three minutes after the circulation fans were started the fuel/air ratios were equalized throughout the tank. It is a quite reasonable assumption that the optimum conditions for combustion in the TWS will correspond to the highest overpressures in the ullage sampler. It is the authors' opinion that this ullage sampling system is extremely effective and yet very simple in theory and practice.

The results of the comparisons of the foams indicate that there is no discernible difference in performance between the polyether urethane and the polyester urethane. One of the criticisms of the polyether urethane foams was that they would lose a significant amount of tensile strength in the presence of JF-4. However, there was no apparent increase in damage to the polyether foams as opposed to the polyester type. Also, from handling and observing the foams after removal from the TWS, there appeared to be no difference whatsoever between the two types of foam. In fact, it is the authors' opinion that if both types of foam were of the same color, it would be virtually impossible to distinguish the two types either before or after a test.

The motion picture coverage was very valuable in corroborating the TWS overpressure histories from pressure instrumentation data. In every case where there was no sustained combustion overpressure the motion picture coverage indicated no gases being forced out of the entrance and exit holes or only an initial spurt immediately after the 23 mm HEI blast. If a sustained combustion overpressure was indicated on the instrumentation the motion picture coverage clearly indicated gases being forced from entrance and exit holes for an extended amount of time.

The mechanism by which the foam prevents flame fronts from propagating or explosions from occurring was of some interest in this program. The combustion overpressure data from the tests in this program were generally lower than anticipated, and in most cases there were no combustion overpressures at all. This raised the question of

what is the difference between these tests and those tests done in the flame tube at AFAPL? The main difference is the use of ballistic projectiles in this program as opposed to a spark ignition source in the flame tube tests. However, the 50 cal. API and the 23mm HEI used in this program produce a larger and more intense ignition source than a spark and would therefore tend to produce higher overpressures and not lower ones. The venting from the entrance and exit holes and into the circulation system in some tests effectively lowered the overpressures but not to the extent that was seen. The only other major difference was the fact that the foam was wetted with JP-4 in these tests where as the foam in the flame tube is tested dry. The two tests conducted with dry foam in this program succeeded in verifying that the wet foam does perform significantly better. One theory as to how the foam works is that the foam itself acts as a heat sink to which heat from the flame front is transferred. This heat transfer from the flame lowers the temperature of the reaction enough to slow the reaction rate dramatically or actually stop the reaction totally. Some of the factors which would affect this would be surface to volume ratio of the heat sink (i.e. foam and/or fuel droplets), specific heat of the heat sink ( $C_p$ ), and the latent heat of vaporization of the fuel. The wet foam has more mass and therefore is a greater heat sink. It also effectively increases the surface to volume ratio of the foam. The specific heat of urethane and fuel are approximately the same, therefore the fuel would not effectively increase the specific heat of the foams.

There is a difference in the amount of fuel retained in the foam depending upon the drain rate. Drain rate will be defined, for the

purposes of this report, as the rate at which the level of the liquid JP-4 drops through the foam. For this program the drain rates were in the neighborhood of 15 cm per minute and were not controlled or thought to be of any significance during the initial test planning or most of the testing. Only after the overpressure data was observed to be low for nearly all tests was this considered. Drain rates in the neighborhood of 2.3 cm per minute are considered to be typical in most aircraft which is significantly lower than used for these tests. It was documented by Mr. T. O. Reed (ASD/EN) via simple fuel retention tests (data presented in Appendix C) that there is an average 25% increase in fuel retention at a drain rate of 14 cm/minute as opposed to a 2.3 cm/minute rate. There could conceivably be a difference in the performance of the foam with different amounts of fuel retention. This was not investigated since it was felt that it was beyond the scope of the program.

The photographs of the exit panel damage, which are presented in Section III, do not indicate any clear differences in damage levels between polyether and polyester foams. There are some small differences between the photographs presented, but these differences do not follow any pattern and are attributed to test-to-test variations in damage. Also, the tests with Astrocoated foam, dry blue foam, and Explosafe did not exhibit any marked changes in exit panel damage. Therefore, for all of the explosion suppression materials tested, there did not appear to be any marked difference in exit panel damage.

It should be noted that the results obtained (the overpressure histories in particular) are peculiar to this test set-up and can vary

well be different for a different test specimen. For example, the overall volume and the amount of venting will have a significant impact on the overpressure history. These tests are meant to be used as a basis for comparing different explosion suppression materials within the test program. Any comparison of results between test programs must be done carefully.

## SECTION V

### CONCLUSIONS

From the results of the tests conducted in this program the following conclusions are presented:

1. The new hybrid polyether urethane foams (i.e. blue foams) performed as well as the standard polyester urethane foams (i.e. red and yellow foams) ballistically.
2. The hybrid polyether urethane foam experienced a loss in tensile strength when in a fuel environment. This reduction in tensile strength was not enough to affect the ballistic performance of the hybrid polyether urethane foam.
3. The ballistic performance of the Astrocoated red foam is equal to that of the uncoated red foam.
4. The limited data indicates that the metal arrester, Explosafe, works as an explosion suppressant material, but a broader data base is needed before it can be incorporated into any weapon system.
5. The performance of foam is significantly increased when it is wetted with JP-4.
6. In the fully packed configuration, the coarse and fine pore foam perform equally well. In the voided configuration, up to 22.6%, both coarse and fine pore foam perform adequately with insignificant differences.



## SECTION VI

### RECOMMENDATIONS

Due to the marked increase in the level of ballistic performance of the foam when wet, it is suggested that a separate program be conducted to investigate in detail the effects of fuel retention. The program should attempt to quantify the increases in performance as a function of fuel retention and investigate the use of higher voiding percentages and/or larger pore size foams since present technology is probably in an "overkill" mode. Many present aircraft installations are probably accepting higher fuel retention/weight penalties than necessary.

In any future experiments with foam in any type of tank where JP-4 is being used and an optimum fuel/air ratio is required, it is recommended that a circulation system be incorporated into the test specimen. There could be several improvements made to this system which would significantly reduce the complexity of the system. Primarily, a better fan or blower could be found which would pump approximately 14 liters/second at a reasonably high  $\Delta p$  across the fan or blower. It was the lack of a capability to produce a high  $\Delta p$  across the fans used in this test which dictated the use of the large diameter ducts so that flow restrictions could be minimized.

APPENDIX A

ULLAGE SAMPLING SYSTEM

Controlling Program

Main Program Bomb

This program controls entrance into one of four tasks by requesting input from TTY (type in number 1, 2, 3, or 4).

<u>Task</u>	<u>#</u>
Initiate	1
Calibrate	2
Manual	3
Scan	4



```

0001      PROGRAM BOMB
0002      COMMON ISUCT, IFILT, ZERO, CS, CAL, LOOKT, IDATA
0003      10 IF(ISSW(3))12,20
0004      12 WRITE(2,15)
0005      15 FORMAT("#.....TASK"//1      INITIALIZE",/,
0006      1"2      CALIBRATE"/"3      MANUAL"/"4      SCAN")
0007      20 WRITE(2,30)
0008      30 FORMAT("ENTER TASK #")
0009      READ(1,*)IT
0010      IF(IT-2)40,50,60
0011      40 WRITE (2,35)
0012      35 FORMAT("INPUT CONSTANT TAPE ON PHOTO READER")
0013      READ(5,*)ISUCT, IFILT, CS, LOOKT
0014      GO TO 10
0015      50 CALL CALIB
0016      GO TO 10
0017      60 IF(IT-4)70,80
0018      70 CALL MANUL
0019      GO TO 10
0020      80 CALL SCAN
0021      GO TO 10
0022      END

```

```

0001  ASMB, P, B
0002      NAM WAIT
0003      ENT WAIT
0004      EXT .ENTR
0005  ICNTR BSS 2
0006  WAIT  NOP
0007      JSB .ENTR
0008      DEF ICNTR
0009      LDA ICNTR, I
0010      CMA
0011      INA
0012      STA JCNTF
0013      LDA ICNTP+1, I
0014      OTA 10B
0015  LOOP  STC 10B, C
0016      SFS 10B
0017      JMP *-1
0018      ISZ JCNTF
0019      JMP LOOP
0020      JMP WAIT, I
0021  JCNTF DEC 0
0022      END

```

```

0001      SUBROUTINE SCAN
0002      DIMENSION IV(9),PMA(9)
0003      COMMON ISUCT,IFILT,ZERO,CS,CAL,LOOKT,IDATA
0004      IV(1)=20020B
0005      IV(2)=20040B
0006      IV(3)=20100B
0007      IV(4)=20200B
0008      IV(5)=20400B
0009      IV(6)=21000B
0010      IV(7)=22000B
0011      IV(8)=24000B
0012      IV(9)=30000B
0013      11 WRITE(2,10)
0014      10 FORMAT("PRESS RUN TO SACN")
0015      PAUSE
0016      C CHICK FOR ABORT
0017      IF(ISSW(0))100,12,12
0018      C*****
0019      12 DO 99 I=1,9
0020      C OPEN V10,V11
0021      CALL RELAY(60000B)
0022      CALL WAIT(ISUCT,4)
0023      C CHECK FOR ABORT*****
0024      IF(ISSW(0))13,14,14
0025      13 CALL RELAY(0)
0026      GO TO 30
0027      14 CONTINUE
0028      C*****
0029      C CLOSE V11,LEAVE V10 OPEN,OPEN V(1)
0030      CALL RELAY(IV(1))
0031      CALL WAIT(IFILT,4)
0032      CLOSE ALL VALVES, START OSCILLOGRAPH
0033      CALL RELAY(1B)
0034      CALL WAIT(5,3)
0035      C TURN ON SPARK, TURN OFF OXCILLOGRAPH START PULSE
0036      CALL RELAY(100000B)
0037      PMA(1)=0.
0038      DO 98 J=1,LOOKT
0039      CALL ADC
0040      X=IAND(IDATA,177700B)
0041      PCUR=((X/3276.8)-ZERO)*CS/CAL
0042      IF(PMA(1)-PCUR)50,98
0043      50 PMA(1)=PCUR
0044      98 CONTINUE
0045      C STOP SPARK, STOP OSCILLOGRAPH
0046      CALL RELAY(10B)
0047      CALL WAIT(1,3)
0048      CALL RELAY(0)
0049      99 CONTINUE
0050      IF(ISSW(1))20,30,30
0051      20 WRITE(2,25)
0052      25 FORMAT(" #1      #2      #3      #4      #5      #6",
0053      1"      #7      #8      #9"/)
0054      30 I=I-1
0055      WRITE(2,35)(PMA(K),K=1,I)
0056      35 FORMAT(9F4.1,2X)/)
0057      IF(ISSW(2))11,100,100
0058      100 CONTINUE
0059      RETURN

```

```

0001      SUBROUTINE CALIB
0002      COMMON II,J,ZERO,CS,CAL,L,IData
0003 C   OPEN VI THRU VIO
0004      CALL RELAY(37760E)
0005      WRITE(2,10)
0006      10 FORMAT("ZERO PFES.; PRESS RUN")
0007      PAUSE
0008      IF(ISSW(0))50,15
0009      15 ZERO=0.
0010      DO 16 I=1,10
0011      CALL ADC
0012      CALL WAIT(1,3)
0013      X=IAND(IDATA,177700B)
0014      16 ZERO=ZERO+X/32768.
0015      WRITE(2,30)
0016      30 FORMAT("CAL. CH.#0","PRESS RUN")
0017      PAUSE
0018      CAL=0
0019      DO 31 I=1,10
0020      CALL ADC
0021      CALL WAIT(1,3)
0022      X=IAND(IDATA,177700B)
0023      31 CAL=CAL+X/32768.
0024 C   CLOSE VI THRU VIO
0025      CALL RELAY(0)
0026      WRITE(2,35)ZERO,CAL
0027      35 FORMAT(F4.2,4X,F4.2)
0028      50 CONTINUE
0029      RETURN
0030      END

```

```

0001  ASMB,R,B
0002  * TAKES ONE READING FROM CH 0
0003      NAM ADC
0004      ENT ADC
0005      COM I(9),IDATA
0006  ADC  NOP
0007      LDA MODE
0008      OTA 11B
0009      STC 11B,C
0010      SFS 11B
0011      JMP *-1
0012      LIA 11B
0013      STA IDATA
0014      ISZ ADC
0015      CLA
0016      OTA 11B
0017      CLC 11B
0018      JMP ADC,I
0019  MODE  OCT 20000
0020      END

```

```

0001  ASMB,R,B
0002      NAM RELAY
0003      ENT RELAY
0004      EXT .ENTR
0005  JR    BSS 1
0006  RELAY NOP
0007      JSB .ENTR
0008      DEF JR
0009      LDA JF, I
0010      OTA 15B
0011      JMP RELAY,I
0012      END

```

```

0001  ASMB,R,B
0002      NAM MANUL
0003      ENT MANUL
0004  MANUL NOP
0005      ISZ MANUL
0006  LOOP  LIA 1
0007      SLA
0008      JMP MANUL,I
0009      AND =B77760
0010      OTA 15B
0011      JMP LOOP
0012      END

```

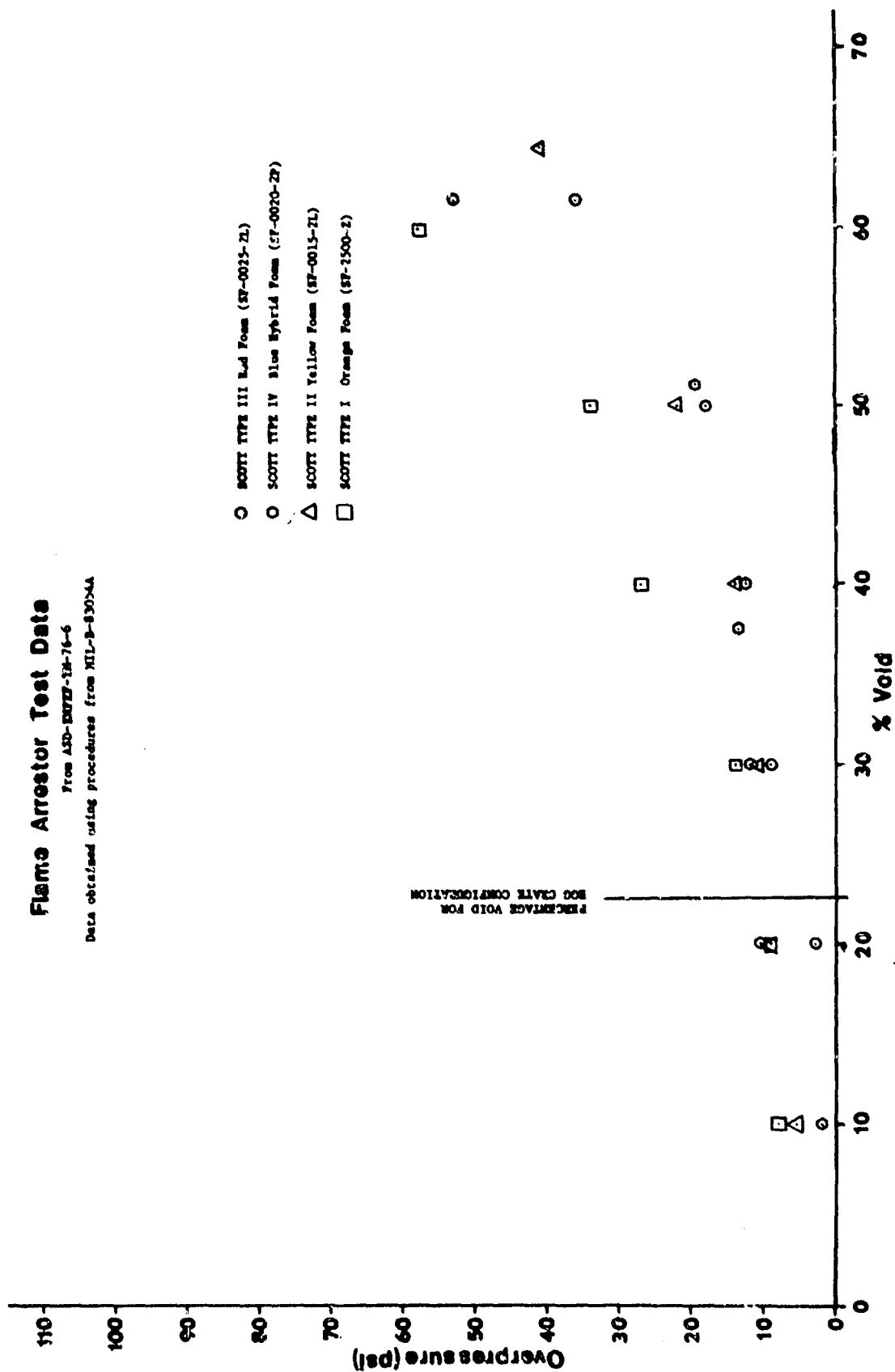


APPENDIX B

FLAME ARRESTOR TEST DATA

# Flame Arrestor Test Data

From ASD-DW73-18-76-6  
Data obtained using procedures from MIL-8-83054A



APPENDIX C

FUEL RETENTION VS DRAIN RATE  
TEST DATA

FUEL RETENTION VS DRAIN RATE  
TEST DATA

Test performed by T. O. Reed (ASD/EN) in Feb  
1976 to investigate the effects of drain rate  
on fuel retention.

<u>Type Foam</u>	<u>Drain Rate (inches/minute)</u>	<u>Fuel Retention (Vol %)</u>
Coarse Blue	.9	1.89
Coarse Blue	5.5	2.30
Fine Blue	.9	2.70
Fine Blue	5.5	3.60
Yellow	.9	.90
Yellow	5.5	1.30
Red	.9	2.91
Red	5.5	2.94

APPENDIX D

PHYSICAL PROPERTIES OF FOAM AND EXPLOSAFE

## HYBRID POLYETHER URETHANE FOAM

## JP-5 FUEL SOAK DATA

## WET TENSION PROPERTIES

TEST CONDITIONS: JP-5 fuel soak at Room Temperature (72°F), all tension data wet except baseline tests run Jun 1975 by Mr. T. O. Need (ASD/ENFEF).

Foam Soak Time	Foam I.D. # W906K(3-1)	Foam I.D. # W906K(10-1)	Foam I.D. # N263 (Run 2)	Foam I.D. # W904K (Run 6)	Foam I.D. # W905K (Run K-2)
BASELINE	17.5 psi	21.3 psi	17.4 psi	18.2 psi	21.6 psi
15 MINUTES	11.7 psi	12.5 psi	11.0 psi	9.5 psi	12.6 psi
1 HOUR	11.2 psi	12.1 psi	9.9 psi	10.0 psi	12.6 psi
4 HOURS	11.2 psi	11.9 psi	10.8 psi	10.1 psi	12.8 psi
24 HOURS	11.5 psi	11.4 psi	10.6 psi	10.3 psi	13.3 psi
MAX. % LOSS FROM BASELINE	36%	46%	42%	48%	42%

AVERAGE LOSS IN TENSILE STRENGTH = 42.8%

## PHYSICAL PROPERTIES OF FOAM

## DATA SUMMARY

PROPERTY	Yellow ID #W852K(2-2)		Coarse Blue ID #W906K(3-1)		Red ID #W881K(2-4A)		Fine Blue ID #W906K(4-3)		Astrocoated Red
	DRY	WET	DRY	WET	DRY	WET	DRY	WET	DRY
DENSITY (lb/ft <sup>3</sup> )	1.34	-	1.38	-	1.36	-	1.385	-	2.15
AIR PRESSURE DROP, AVERAGE (inches H <sub>2</sub> O)	0.155	-	0.200	-	0.289	-	0.264	-	0.252
TENSILE STRENGTH (psi)	25.3	26.0	18.2	10.2	26.2	28.5	22.7	13.0	31.4
COMPRESSION LOAD DEFLECTION @ 25% (psi) 65% (psi)	0.40	0.40	0.57	0.30	0.40	0.37	0.58	0.35	-
	0.60	0.58	0.945	0.545	0.62	0.56	0.925	0.585	-
TEAR STRENGTH (lb/in)	6.8	7.1	5.2	2.4	6.0	6.3	5.51	2.90	-
FLAMMABILITY (in/min)	8.52	-	10.2	-	8.96	-	10.37	-	-
COMPRESSION SET (%)	31.9	-	18.9	-	25.1	-	10.9	-	-
VOLUME SWELL	-	+ 1.4	-	+ 15.1	-	+ 0.5	-	+ 16.2	-

Wet data obtained after JP-4 fuel soaking 1-3 hrs. @ room temperature.  
See Military Specification for explanation of properties/tests.

PHYSICAL PROPERTIES OF EXPLOSAFE  
(Properties of Material as Tested)

## DATA SUMMARY

PROPERTY	VALUE
DENSITY (lb/ft <sup>3</sup> )	2.62
AIR PRESSURE DROP, AVERAGE (inches H <sub>2</sub> O)	.154
VISUAL POROSITY (PPI)	1.3 LWD, 3.5 SWD
ALLOY	SAE 3003 ALLOY H-24 TEMPER
THICKNESS UNEXPANDED (inches)	.003



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